# ELECTRICITY

## MADE SIMPLE

HASKINS

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# ELECTRICITY MADE SIMPLE

*And Treated Non-Technically*

AN INVALUABLE TREATISE FOR ENGINEERS, DYNAMO MEN, FIREMEN, LINEMEN, WIREMEN AND LEARNERS FOR STUDY OR REFERENCE


BY

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*ILLUSTRATED*


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# PREFACE.

THIS little work is not intended for the instruction of experts, nor as a guide for professors. The endeavor has been throughout the book to bring the matter down to the level of those whose opportunities for gaining information on the branches treated have been limited.

That it may prove to them an incentive to more thorough and deeper research, is the earnest wish of

THE AUTHOR.

Chicago, 1900.

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# Electricity Simplified.

## CHAPTER I.

### STATIC ELECTRICITY.

1. Electricity is the name by which we recognize that which produces electrical phenomena. We know it as we know heat and light, by the effects produced. All forms of electricity from the lightning's flash to the feeble manifestation of attraction shown by a rubber comb for the hair it passes through are considered as the same, differing only in the quantity and pressure of the force which produces these results.

2. It is generally assumed to be a result of the vibrations of a subtle fluid pervading all space which is also the transmitting medium of light and heat. This substance is known as luminiferous ether.

3. Electricity is capable of developing results which we may class as simply experimental or laboratory effects, useful effects, and destructive effects.

*Experiment 1.* If on a cold, dry day a person skips rapidly over a thick carpet and immediately brings a finger near a gas or water pipe a spark will issue from the finger to the pipe with a slight, snapping noise. If the conditions are favorable the spark may be discharged to a stove pipe, to a second person's face or hand.

*Ex. 2.* If a common hairpin or a bit of wire be twisted on a gas burner in such a way as to bring one end directly over the opening, and, while a second party turns on the gas the charged finger be brought to the end of the hairpin, the spark

will be discharged directly through the escaping gas, and set it on fire.

*Ex. 3.* Briskly rub a sheet of paper which is lying on a polished desk, with a rubber eraser, or even the hand, in a cold, dry room, and the paper will stick to the table. If a second sheet lies below it, and the two are forcibly separated, they will then repel each other.

*Ex. 4.* Draw the fibre of a silk cocoon briskly between the thumb and finger, in a cold, dry room, and it will show an inclination to attach itself to the other hand; but having once touched, it will incline to keep aloof from the hand. In this way alternate sections of the fibre may be made to attract and repel the hand.

*Ex. 5.* Lay a glass rod on a table, one end of which extends over the edge a few inches. Attach to this a silk cocoon fibre, fastened to the lower extremity of which is a small ball of pith from an elder or a cornstalk. Rub a second glass rod with a silk handkerchief, and present it to the pith ball. It will be strongly attracted, but almost immediately repelled, and it will not readily touch the glass again. Now rub a stick of sealing wax or a piece of wood highly polished with shellac varnish, with a woolen cloth, and present this to the ball which will attach itself as before, and then be repelled. If now the glass rod be again rubbed and brought near the ball it will be attracted and then repelled as before. Thus we may repeat the attraction and repulsion phenomena as often as we change the freshly rubbed articles.

*Ex. 6.* Take a pair of common India rubber toy balloons fully inflated, and rub these briskly together, when, on presenting them to the pith ball it will be seen to be attracted and repelled alternately, by either, playing like a pendulum between the two until the charge is exhausted. But if the two balloons are brought into intimate contact after rubbing, the ball will be uninfluenced by either.

4. Explanations. The fact that under one set of circum-

stances certain electrified bodies manifest a disposition to be drawn to other bodies, and at other times are repulsed by the same bodies, plainly indicates that there are two electrical conditions.

5. These two conditions, formerly known as vitreous and resinous electricity, are to-day known as positive and negative electricity—different conditions of the same force.

6. The former is often abbreviated by the use of the sign + and the latter by the sign —.

7. These two conditions have an affinity for each other, that is, an attraction which is mutual, and when brought together in equal amounts and pressures, they mingle and cease to be appreciable—they disappear.

8. But when two bodies similarly electrified are brought near each other their tendency is that of repulsion, from which we learn that when the pith ball is touched with the glass rod it is attracted, and receives a portion of the charge from the rod. It is now similarly charged or electrified, and is immediately repelled; but on approaching it with the resinous body it is attracted because this last is electrified by a different polarity. No sooner does it attach itself to this, than it loses its former condition, by the neutralizing effect of the new electrification, and being in a neutral condition it takes part of the charge of the fresh application, and then, the two being similarly electrified, repulsion results. We have also seen that a neutral or unelectrified body is attracted by either a positive (+) charge or a negative (—) charge. From these demonstrated facts we deduce the following:

9. Similar electrical charges repel each other. Dissimilar electrical charges attract each other. Either electrical condition may show attraction for an unelectrified body.

10. Different electrical conditions are produced by different treatment of the bodies so electrified. The glass rod rubbed by a silk handkerchief induced a condition which was unlike that induced by the flannel's friction on the wax or shellac.

11. Slight differences may lead to these varying results. In the case of the two rubber balloons the material and all the circumstances would seem to be precisely similar, but the result, one being positively and the other negatively electrified, shows that there is an unobserved difference.

12. Experiment has shown that where two pieces of the same material are rubbed together, if one is colder or smoother than the other it will show + electricity, and the warmer or rougher will show a — charge. A white silk ribbon rubbed on a black one of the same kind and quality, shows + electrification. Wind blowing on a glass plate develops + electricity. High pressure steam issuing from a minute hole will develop electricity. Locomotives occasionally show electrical phenomena when blowing off steam through safety valves.

13. The rubber may determine the sign (whether + or —), of the electricity developed. A glass rod rubbed by cat's fur in place of silk, will show the opposite form of electricity; it will be — instead of +.

14. If any one of the following articles be rubbed by one which stands above it in the list, the rubber will be positively electrified, and the rubbed will be negatively affected; and if a lower article take the place of rubber, the reverse will be the result.

| | | | | | |
|---|---|---|---|---|---|
| 1. | Cat's fur. | 4. | Paper. | 7. | Shellac. |
| 2. | Polished glass. | 5. | White silk. | 8. | Ground glass. |
| 3. | Wool. | 6. | Black " | | |

15. In the above experiments we see that electricity is capable of developing the various phenomena of Attraction, Repulsion, Heat, Light, and Physical effects, all which are results of mechanical movement—friction. This is known as a transformation of energy, or the power of accomplishing work. The total amount of energy in the universe is always the same. It is indestructible, but may appear under various forms, and undergo various changes, appear and disappear, but is never

lost, and the total quantity can neither be augmented nor diminished, but under certain circumstances may become unavailable.

16. This form of electricity which has been thus far considered, is known as static or frictional electricity, and the results mentioned are those of a purely experimental character, dealing with the most diminutive and harmless exhibits of electric power.

17. Static electricity may be generated by machinery. We often see it in the swift moving leathern belting of a shop or factory. Sparks may be sometimes drawn several inches from such a source, and are accompanied by a sharp, snapping sound. Plate machines, consisting of one or more discs of glass, arranged to revolve on a central axis, having proper attachments for developing the electricity and conveying it away are made, which are capable of sending sparks many inches through dry air, between the + and — terminals of the machine.

18. These sparks may be massed or collected in a proper receptacle,—a Leyden jar—until the accumulation is dangerous to handle or discharge except with some metallic contact apparatus.

19. A Leyden jar consists of a glass jar or water bottle coated with tin foil for about eight-tenths its height from the bottom, both inside and out. Through the cork which closes the mouth there is a metallic rod—usually brass—the upper end projecting somewhat above the cork, and terminating in a ball. The lower end of this rod is in contact with the inner coating of the jar, either directly, or by means of a chain. A simple and cheap method of substitution for the inner foil, which is difficult of placing, is filling the space with chain or crumpled tin foil taken from packages of tobacco. The inside of the jar having been thoroughly dried, the cork is varnished with shellac, and the neck is also covered with the same, a thick coating being laid on in each case.

20. Now, on connecting the outer coating with the earth by a metallic conductor—a chain or wire—and connecting the ball of the rod with the electrical machine the sparks will be discharged into the jar, and as the two surfaces of the jar are of opposite polarity the electricity is held "bound," as it is called, and can only be readily discharged by contact being made between the outer and inner surfaces.

21. With the connections arranged as above the inner portion of the jar becomes positively charged. We have seen how similar polarities repel each other. The negative electricity is drawn to the outside of the jar and the positive is repelled by the inside charge.

22. Changing the connections will reverse the polarities.

23. This action is one of induction, of which we will learn more in a coming chapter.

## CHAPTER II.

### STATIC ELECTRICITY (CONTINUED).

24. Formerly a distinction was made between what were known as electrics and non-electrics, or bodies which can or cannot be electrified by friction. Even the metals may be so electrified, but the experiment must be so conducted as that the electricity generated will not escape as fast as developed.

25. To properly test this quality the metal, say an iron rod, must be attached to some substance which does not readily carry electricity, or afford a path by which the electricity may escape. If attached to a glass rod by which it is held and is then struck with a cat skin or flannel the iron rod will be quite sensibly excited; and a test will determine which of the two conditions, + or —, is present. All bodies, so far known, are thus susceptible of being electrified.

26. It is also true that all known bodies are, to a greater or less extent, conductors of electricity; or bodies over which a charge of electricity will spread. But practically there are many substances over which a charge is so slowly carried that we know them as insulators or non-conductors, while those which are much better mediums for the transmission of electricity are called conductors. The following table will show the gradations from very good to very poor conductors, No. 1 being best and No. 21 the poorest of so-called good conductors:

| | | |
|---|---|---|
| 1. Silver (annealed). | 8. Iron. | 15. Ores. |
| 2. Copper (annealed). | 9. Lead. | 16. Sea water. |
| 3. Silver (hard). | 10. German silver. | 17. Spring water. |
| 4. Copper (hard). | 11. Mercury. | 18. Rain. |
| 5. Aluminum. | 12. Charcoal. | 19. Snow (wet). |
| 6. Zinc. | 13. Acids. | 20. Animals (living) |
| 7. Platinum. | 14. Salt solutions. | 21. Damp Earth. |

27. Insulators, or very poor conductors, are classified as follows, the best insulator being No. 1; the poorest, No. 15:

| | | |
|---|---|---|
| 1. Dry Air. | 6. Shellac. | 11. Porcelain. |
| 2. Sulphur. | 7. India Rubber & Gutta Percha. | 12. Earthenware. |
| 3. Glass. | | 13. Oils (clean). |
| 4. Paraffine. | 8. Resins. | 14. Paper. |
| 5. Ebonite or bone rubber. | 9. Silk (uncolored). | 15. Marble. |
| | 10. Dry Wood. | 16. Slate. |

28. We are now better able to comprehend what is meant when insulation or insulator is mentioned, and also the meaning of conductor and conductivity.

29. We have now to investigate another property of electricity which is called induction--a movement of electricity itself, resulting from the attraction or repulsion of other electricity—that is, electricity developed by one source may induce motion in electricity in its vicinity developed from some other source.

30. In the Leyden jar this action was evident, the charge inside the jar influencing the electricity surrounding it, driving off that of the same sign, and attracting to itself that of the opposite sign. A proof of this action can be very prettily shown by the following:

Experiment.—A sphere of metal, or of wood, covered with tinfoil is mounted on an insulating stand—a wooden stand with a glass rod for an insulator. A second similar stand has a horizontal cylinder of conducting material or wood covered with foil, hanging from which are loops of silk; and to these, two or three inches below the cylinder, are fastened little balls of pith. These loops are four or five in number and are distributed along the cylinder at regular intervals. The little cylinder, say an inch in diameter and about six inches long, is now insulated from the ground. If the ball is charged by any source of frictional electricity and brought near one end of the cylinder, each pair of the little pith balls will show

repulsion, and remain standing apart. Those at the two ends of the cylinder will show a greater repulsion and remain farther asunder than the pairs near its center. And now if we excite a rubber comb or rod of glass by rubbing it, we will see that on approaching the pith balls it will attract those at one extremity of the cylinder, and repel those at the opposite end, thus showing the extremes of the cylinder to be of opposite polarity.

31. This proves conclusively that the approach of the charged ball separated the two electrical conditions on the cylinder, attracting the opposite polarity and repelling the similar polarity. And further shows that similar polarities repel each other because each pair of pith balls was similarly charged with either + or — electricity.

32. For this and other simple experiments with static electricity we may substitute for a static machine, the swift running belt of an engine room, and an incandescent lamp; even one disused and burned out, if there is no leak in it, makes a good Leyden jar or receptacle. Holding it in the hand, beneath the belt, the sparks will pass into it until a very considerable shock may be received by bringing the other hand in contact with the metal part of the lamp. Be very careful not to overload the lamp, as it is capable of giving a powerful shock. A harmless discharge may be shown by means of a well insulated wire one end of which is attached to a ground (water pipe or engine pump), while the other is touched to the butt of the lamp. The Leyden jar is one form of condenser.

33. A second form of condenser may be constructed of sheets of tinfoil and paraffined paper. These are laid alternately, so that the odd numbered sheets will project a trifle over one side, and the even numbered sheets over the other. Put this together dry and warm, and having pressed it tight and bound it with something not a conductor, the edges of all the odd numbered sheets are made to touch and the even numbers the same. You now have virtually but two large sheets of foil,

separated by an insulator. A terminal connection is now fixed to each of the poles and you have an instrument quite similar to a Leyden jar, capable of receiving and containing electricity, of producing shocks, of testing polarities of other charged bodies, etc.

34. To successfully charge a condenser or a Leyden jar, some connection is necessary from one side or pole of the former, or from the outer coating of the jar to the earth, in order that the opposing electrical condition may be attracted, and the similar condition be repelled. This may be done through the medium of the human body, by a chain or wire in connection with the floor, or any system of pipes in the room which lead to the earth.

35. In all that we have seen of static electricity we are constantly reminded of the fact that it possesses a power to escape which enables it to cross a considerable space of one of the best insulators known—in fact, the best, according to some authorities—dry air.

36. This is because of a property inherent in all forms of electricity, which is in excess in static electricity, and quite the reverse in battery current and the currents used for electroplating, or the deposition of metals from a metallic solution.

37. This property of electricity is known as electrical potential. It corresponds somewhat to pressure in steam, pressure of a column or tank of water—pressure or strain of any fluid which is held by constraint above or below the surrounding level. The farther away, perpendicularly, from the sea level a column of water rises, the greater the strain, and the disposition to descend. The steam in a boiler, if permitted, will blow off until the equilibrium is found, and an air brake tank or a vacuum cylinder will always seek a pressure level. In the one case the pressure is outward, and in the other inward—but in either case there is a potential difference, a pressure from one to the other level.

38. A second property of electricity is rate of current flow. This is a matter of quantity, and we may again compare this property of electricity with a property of steam, of water, etc.

39. If we have a tank of water lying nearly level with the ground, a large shallow tank, and make an opening, the water will flow freely, but with little pressure as compared with similar conditions in a flow from a higher head, and much less water would be carried off in a given time in the former case. So with steam, if we can think of height in the one case being comparable with pressure in the other.

40. Static electricity, such as we have been studying it, is, in short, a charge in which the one element of quantity is almost wanting, while the element of pressure is in excess. In the electro-plating form or condition the reverse is most perfectly seen. With every inducement to escape which dampness can offer, the current is handled with impunity, and yet readily accomplishes the breaking up of metallic solutions, and depositing the pure metal in a solid mass.

41. These two properties of electricity are found combined in varying proportions, of which the comparison just made shows two extremes. In the lightning's flash we have the two combined in the most magnificent aggregations.

42. Water flowing through a pipe, or coursing down a channel meets with obstructions to its even flow, and is retarded by the obstacles in its path. A stream of water in which there is a generous growth of grass has but a sluggish current, where the descent is steep enough to cause a current of four or five miles per hour, if the resistance caused by the obstruction could be removed. Steam issuing from a boiler into the open air is obstructed in much the same manner. In mechanics this is generalized under the term friction. Opposition to the action of electricity which we call flow of current, is known as resistance.

43. Now, the power to overcome resistance in water is head (pressure), in steam it is pounds (pressure), and in electricity it

is potential difference, head (pressure), electrically called electromotive force. Here are three factors which combine to define all electrical action. These factors are:

Electromotive force — written E, or E. M. F.
Resistance . . . . — written R.
Current flow . . . — written C.

44. A moment's consideration will show the reader that the delivery of water (or electric current) will depend on the head (or E), divided by the friction (or R), and this as a formula $C=\frac{E}{R}$ is known as Ohm's law, which we understand to mean: the flow of current in an electrical conductor is equal to the original electrical supply divided by the obstruction offered to the electrical movement, or, abbreviated; Current equals the electromotive force divided by the resistance. This law is more particularly applicable to electricity developed by batteries or dynamos, for these developments are of a flowing character rather than fitful discharges, and we shall learn more of it in a coming chapter.

## CHAPTER III.

### STATIC ELECTRICITY (CONTINUED).

45. A very simple and inexpensive piece of apparatus, called an electroscope, may be constructed with which we may be enabled to test whether a body is, or is not, electrified ; and if so, of what sign its electricity is.

46. Take a large lamp chimney, such as is used for a study lamp, or an open-mouthed glass fruit jar, and on the inner surface paste two strips of tin foil, opposite each other. wide enough to reach one-quarter round the glass, and to cover about three or four inches up from the bottom. Fit a cork into the neck, and through this pass a brass rod, reaching nearly to the upper end of the foil. Attach to the lower end of this rod two very fine linen or silk fibers, with a small pith ball or bit of cork fastened to the lower extremity of each. To the upper end of the rod solder a disc of tin—or better, as we shall presently learn, a ball of metal. Next, put the rod and its attachments into the jar, and close it with the cork. This should all be done in a dry and preferably in a cold, or at least a cool room, to prevent moisture getting into the jar.

47. The cork, too, must be thoroughly dried and well coated with beeswax or paraffin, and then well varnished with shellac, and the top of the chimney or jar also varnished. Now, when the chimney is cemented in a standing position to a disc of wood, and thoroughly shellacked, it will be ready for use.

*Experiment 1.* In a dry, preferably a cold atmosphere, if we develop a small amount of + electricity by rubbing a glass rod with a piece of silk, and nearly touch the upper terminal of the brass rod, if all the conditions are favorable, we shall see the little balls of pith stand apart from each other ; for the charge which is received from the glass rod by the ball, repels

the similar sign or + polarity into the leaves, and these, by the same law, being of similar sign, repel each other. With the influencing body—the glass rod—in that position, touch the ball with your finger. The pith balls will instantly drop, and the insulated combination of ball, brass rod and pith balls, having been discharged of their repelled or + electricity to ground, through you, are now in an opposite electrical condition, and attracted to the glass rod. Remove the finger, and now, when the glass rod is taken away the pith balls will again repel each other, because the attractive influence of the glass rod is removed, and the opposite form of electricity, the —, is now spread over the ball, brass rod and pith balls. Now if another electrified body is brought as a test near the upper terminal of the metal rod, and the divergence is increased, it is plain the charge is similar to that of the pith balls ; but if the pith balls do not diverge, then their charge, being of the contrary sign, is attracted to the testing body, and away from the pith balls.

48. For a more sensitive form of electroscope gold leaf is substituted for the thread and pith balls ; but while more delicate, it is far more liable to injury than the apparatus described.

49. Even simpler methods may be used to test the electrification of a body, as the reader will comprehend by reference to a former experiment in attraction and repulsion (3, Ex. 5). After the pith ball of an electric pendulum has touched the source of electricity, if it is attracted by the approach of a silk rubbed glass rod, its charge is —, but if it is repelled the charge is + ; or if it is attracted by fur-rubbed shellac or resin it is +, and if repelled it is —.

50. Static electricity resides on the surface of the charged body.

51. This law does not obtain in electric currents, and is subject to an exception whenever an inducing or charged body completely surrounds a charged body, if insulated from it.

52. There are several methods of demonstrating this peculiarity. The most complete illustration is due to Faraday.

*Experiment 1.* On the top of a rod of glass which is fastened to a sufficiently heavy base, a brass ring is fixed in a vertical position. To this ring, much like a minnow or landing or butterfly net frame, is attached a fine linen bag, which runs down to a point—an elongated cone. A silk thread extends from the apex or point of the cone, in each direction, so that the bag may be reversed at will by pulling on the one thread and loosing the other. Now, when this bag is charged a test shows electricity on the outside, and none on the inside of the net, in all cases. Reversing the bag reverses the surface electrified, no matter how often or how suddenly the change is made.

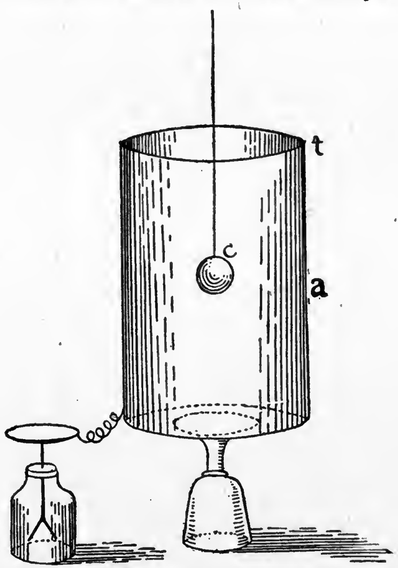



FIG. I. INDUCTION OF AN INSULATED CHARGE.

*Experiment 2.* Take an insulated metal pail, a, Fig. 1, and connect a gold leaf or other sensitive electroscope e, and provide a brass ball c, to which attach a white silk thread—three or four feet long—to thoroughly remove the influence of the hand on the pail. Now, having completely discharged a, let c be charged, and without handling it except by the silk thread, lower it into a, without contact. The gold leaves will diverge, and this repulsion will continue to increase until c is a certain distance below the top of the pail t, when they will become stationery, and remain so. Touching the bottom of a with c will discharge the latter, and there will be no movement to indicate a change in the electrification of e, which shows that the charge of a, developed by induction from c, is exactly equal to the original charge of c.

*Experiment 3.* Provide four pails of such sizes as to permit of their being placed within each other—a nest—and insulated from each other, the outer one connected to an electroscope as before. Now, when the charged ball c is introduced into the inner pail and touches the bottom, the gold leaves will act precisely the same as before. Lift out the inner pail by an insulating silk thread, and the gold leaves will collapse. Introduce the pail again and they will diverge as before, and connecting the pails together by wire handled by a silk cord will not change the position of the leaves. Discharge the inner pail by a ground contact and the leaves will collapse. This is also due to Faraday who, to prove that there is no force within any hollow electrified conductor, provided it has no connection with bodies external to it, constructed a cubical box—twelve feet each way—covered externally with tin foil and copper wire, well insulated from the earth. This he charged heavily from an electrical machine, but a gold leaf electrometer inside the box remained unaffected. He says: "I went into the cube, lived in it, using lighted candles, electrometers, and all other tests of electrical states. I could not find the least influence upon them or indication of anything particular given

by them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every part of its outer surface."

53. For developing comparatively small charges of electricity a very simple apparatus, called an Electrophorus, is used.

54. This apparatus usually consists of a cake of common resin and of a polished metal disc, with an upright, insulating handle. The resin is electrified by rubbing or striking it with a piece of catskin or flannel, and then placing the metal disc upon it. The metal plate does not now receive a charge, but if touched with the finger to connect it to earth, and the plate is then lifted by its insulating handle, it will show by any test we may apply that it has received a charge, and will part with more or less of it to any neutral or uncharged conductor with which it may come in contact. If touched with the finger a spark will pass which will almost or quite completely discharge the disc. The electricity in this case is equalized by electricity of opposite polarity from the earth.

55. An electrophorus is quite easily constructed. For the base a tin pie plate may be used. Fill this with broken resin, and melt it down into a solid cake, as nearly level full as possible. Melt it by setting it in a dish of hot sand or water, removed from the fire, to prevent it from accidentally taking fire.

56. Now get a piece of tin a shade smaller than the resin cake, and fasten it to an upright handle of wood which has previously been well polished with shellac varnish. A screw will fasten the two together. Add to this a dry, soft piece of catskin* or a piece of thick flannel, and the apparatus is complete.

57. In former paragraphs (35 to 39), mention is made of electrical pressure, or potential, which is now to be considered more in detail. Electric energy is the capability or power of accomplishing electrical work or results, and depends both on

*A living cat, if perfectly dry, held by its legs, makes an excellent rubber.

the amount of electricity or quantity, and on the difference of electrical level between two places; or, the difference of potential. This is usually, and most readily as well, illustrated by comparison with the action of water. We say that Lake Superior, for instance, is 600 feet above the level of the sea, and about 22 feet above the level of Lake Huron. There is, then, a pressure—a potency or power—greater in Superior than in Huron, which is only held back by the restraint of intervening soil and rock. Remove these and the water would at once equalize its pressure, and, after a few surgings back and forth, assume a quiet level. Yet it would still have a higher potential than the waters of the ocean, the base line from which all altitudes are reckoned. But depths are also calculated from the same zero or base line, and the water in a mine may be many hundred feet below that line. All water below that level, then, we may compare to negative or —, electricity, and all above that level to positive or + electricity.

58. The earth is to electricity levels what the ocean is to water levels: a zero point. Where a positive electrical condition exists its potential is above the level, and where a negative electrical condition exists the potential is below that level. When there is no electrical condition manifest, there is no potential difference.

59. We may fix another fact firmly in our minds by a second comparison. Imagine a teter or see-saw, which as to length is perfectly balanced. If we add weight to one end we throw it out of balance, and that end goes down, but the other end goes just as far in the upward direction. No matter what amount of electrical potential we develop, whether + or — the act of so making electricity manifest develops just so much of the opposite sign. The electrical teter, like a board see-saw, goes up at one extremity as far as it goes down at the other; and its tendency is to find the level or zero point. Forced, by raising or lowering its potential, it shows a tendency to restore its equilibrium by uniting the + and — conditions, accomplishing which it ceases to manifest itself.

60. This act, the mingling of the two electrical conditions is what we accomplish when we discharge an electrified body by what is known as a disruptive discharge. An electro-static (electricity in a state of rest) machine, by which more positive demonstrations may be shown, is one in which the electricity evolved is gathered as it is developed, and may be collected by means of proper appliances until the discharge of such an accumulation through the human body would be fatal.

61. The best known of the form which depends for efficiency on friction consists of a glass cylinder, or disc, against which two padded leather rubbers press, these latter being coated with an amalgam of mercury, zinc and tin, made to adhere by being mixed with a stiff grease. The whole is well insulated, and as the glass is revolved the + electricity developed on the glass is carried away by a number of stationary combs or discharging points which nearly touch the glass, to the positive terminal of the machine, while that of the rubbers is conducted to the negative terminal. If + electricity is required the — terminal is connected to earth, but if — electricity is desired, the opposite terminal is so connected. If the two terminals are brought sufficiently near each other, a disruptive discharge will follow, and sparks will flow as long as the machine is actuated. To accumulate the electricity the leyden jar is made the receptacle by being brought within sparking distance of one terminal, while the other terminal of the machine and the outer coating of the jar are grounded.

62. This form of electrical machine has been almost completely superseded by more successful apparatus, called influence machines.*

63. The influence machines depend, for their efficiency, on the principle of the electrophorus. The action of charging and discharging is made automatic and continuous, and the

*The first electrical machine was invented by Otto Von Guericke, 1602-1686, and consisted of a sulphur ball, rotated on its axis, while a second person produced the necessary friction by holding his hands on the ball.

electricity may be accumulated by means of a condenser, either a leyden jar or one of the form described previously. (33).

64. There are many forms of influence or induction machines of which the Holtz is a representative type, and is shown in Fig. 2. As a class these may be designated as electrostatic machines requiring to be primed with a slight initial charge, which latter, by its inductive effect on a rapidly revolving disc of some dielectric material, builds up a greatly superior charge of electricity.

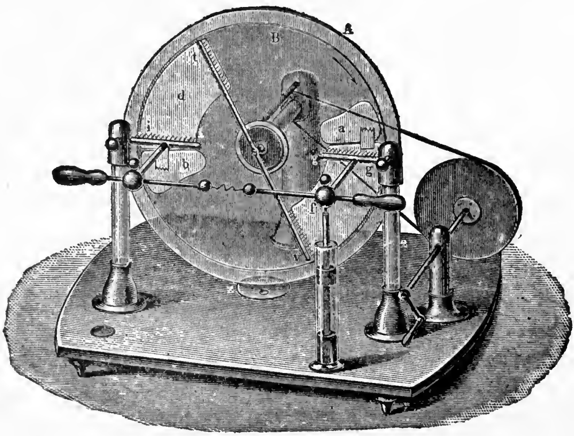



Fig. 2.

HOLTZ MACHINE.

65. The various parts of a Holtz machine (Fig. 2) are :

(1) A stationary glass plate A, held in position by insulated supports.

(2) A second glass plate B, capable of being revolved quite close to, but not touching the plate A.

(3) Two segments, called armatures, *d*, *f*, of varnished paper, firmly fixed on the farther side of the fixed plate at holes cut in the plate, called windows, *a*, *b*. Attached to these armatures are tongues of paper shown as extending over *a*, *b*. The arrow shows the direction of rotation.

(4) Two metal combs or rakes, *g*, *i*, are in close proximity to the revolving plate, and are connected metallically to the discharging rods which terminate on the front of the machine, between which is a representation of a passing spark. By means of insulating handles the distance between these terminals may be varied as required.

66. The whole is supported on glass to insure as perfect insulation as possible.

67. To operate the machine the discharging terminals are placed in contact. A small initial charge or priming is given to one of the armatures by holding an electrified body (preferably excited hard rubber) against it, and revolving the plate by the handle. Gradually separating the terminals the increasing distance will be overcome by the passing spark, the snap becoming louder with distance, until the separation is too great. Closing the gap will show the sparks again.

68. In the Holtz machine we have a species of automatic electrophorus, the action of which is thus described by Prof. S. P. Thompson:

69. "Suppose a small + charge is imparted at the outset to the armature *f*; this charge acts inductively across the discs upon the metallic comb, repels electricity through it, and leaves the points negatively electrified. They discharge —ly electrified air upon the front surface of the movable disc; the repelled charge passes through the brass rods to the balls, and is discharged through the left comb, upon the front side of the movable disc. Here it acts inductively on the paper armature, causing that part which is opposite to itself to be negatively charged and repelling a + charge into the tongue, which being

bluntly pointed, slowly discharges a + charge on the back of the movable disc. As the disc is turned farther this + charge on the back comes over from the left to the right side, as shown by the arrow, and when it gets opposite the comb, increases the inductive effect of the already existing + charge on the armature, and repels more + electricity through the brass rods and knobs into the left comb. Meantime the — charge, which we saw had been induced in the left armature has in turn acted on the left comb, causing a + charge to be discharged by the points on the frontof the disc; and drawing electricity through the rods and knobs, has made the right comb still more highly —, increasing the discharge of —ly electrified air upon the front of the disc, neutralizing the + charge which is being conveyed over from the left. These actions result in causing the top half of the moving disc to be —ly electrified. The charges on the front serve, as they are carried round, to neutralize the electricities let off by the points of the combs, while the charges on the back, induced respectively in the neigborhood of each of the armatures, serve, when the rotation of the disc conveys them round, to increase the inductive influence of the charge on the other armature."

70. A quite radical departure from the Holtz machine, of which there are several modifications, is the Wimhurst machine which, like the former, is a convective or silent inductive machine. Fig. 3 represents the Wimhurst electrical machine. In this apparatus the two glass plates, which are well varnished with shellac, are rotated rapidly in opposite directions. On the outside of each of the plates, tin foil strips are arranged like the spokes of a wheel. These serve both as inducing and conveying mediums, the carriers of one plate acting inductively on those of the other. Two bent brass rods with brushes of fine wire at either extremity lightly touch the plates as shown. An U shaped comb, the points of which barely escape them, embraces the two plates. Now, on turning the handle the little brushes set up a minute charge on the outer surface of the

glass, each little sector becomes an inductor of the opposite one—and a carrier as well—giving up its charge at the comb when passing it.

71. The Wimhurst machine, having as many as thirty or

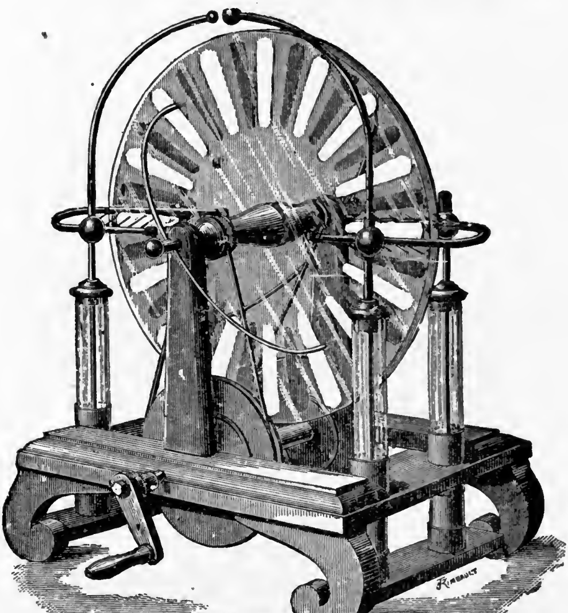


Fig. 3.

WIMHURST MACHINE.

forty sectors, each of which is gathering and discharging electricity, has proven the most successful machine known, inasmuch as it requires no initial charge to "prime" it; it "builds

up" to its capacity more readily than any other form of machine and is less affected by atmospheric conditions.

72. In all the better forms of such induction or convection machines,* there is usually attached, as part of the apparatus, two stationary leyden jars, one on either the — and the + side. The charges of these will of course be reversed to each other, the inside of one being — and the other being +, and consequently the outer coating of the first will be +, while that of the second will be —. A disruptive discharge between the two discharging terminals will also provoke a discharge between the outer coatings of the two jars in the opposite direction.

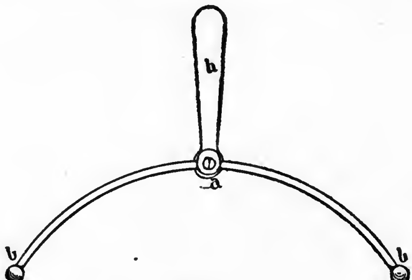



Fig. 4.

DISCHARGING TONGS.

73. For safely discharging a leyden jar, a discharger (Fig. 4) is necessary. This is made similarly to a pair of callipers, a hinge at a allowing of changing the distance between the balls, b. All save the insulating handle, h, is of brass. A fairly convenient discharger may be made of a piece of well insulated wire cable, the two ends of which terminate in balls. Lead bullets may be used for these terminals, or wooden balls, if these are well covered with tin foil.

*Convective discharges are those in which a discharge, usually silent, occurs through particles of repelled air, which being repulsed carry away minute portions of the electricity of a charged body.

74. With the discharger, we bring the outside and the inside of the jar into metallic contact; the equilibrium between the two coatings—inside and outside—will be established or equalized without danger of shocking the experimenter. Always make the contact with the outside first.

*Experiment 1.* A piece of cardboard held between the knob of the charged leyden jar and the discharger will be perforated by the escaping spark. The perforation will show a burr edge on both sides of the card.

*Ex. 2.* A thin sheet of glass may be fractured in the same manner with a sufficient charge.

*Ex. 3.* Let a small length, say a couple of inches, of fine glass tube be filled with water and tightly corked and sealed at each end. Through each cork put a fine wire—a large-headed pin or a round head finishing nail—leaving some space between their inside ends. Place this on the table, one terminal touching the jar. Bring one terminal of the discharger to the opposite end of the tube and make a quick contact with the other terminal and the ball of the leyden jar. If all the conditions are favorable the commotion inside the tube will shatter it.

*Ex. 4.* Insert two round-headed, blunt-pointed finishing nails in a bit of dry wood; bring the points of the nails within an eighth of an inch of each other, and a discharge will rupture the wood.

*Ex. 5.* An electric cannon. Take an inch-long piece of small glass tube, fit a tight cork of beeswax, through which as far apart as possible stick a pair of small brass wires at one end, and loosely fit a pith ball in the other. A discharge from a leyden jar from one of the wires to the other through an air space of an eighth of an inch, will fire the cannon, showing another form of mechanical effect from electrical action.

*Ex. 6.* A still more startling result may be produced by the ignition of hydrogen gas, resulting from the decomposition of water, when this is mixed with the oxygen of the atmosphere.

Into a strong bottle put a mixture of water and sulphuric acid, in the proportion of one of the former to six of the latter, gradually mixed. Now drop in a few pieces of broken zinc. An ebullition will commence at once, the oxygen of the water attacking the zinc, forming an oxide of zinc; this combines with the sulphuric acid forming a sulphate of zinc; hydrogen gas is set free and rises in the form of bubbles to the surface, and mixes with the air in the bottle. This mixture of the hydrogen from the water and the oxygen of the air is highly explosive. If we now form a contact between the two surfaces of a charged leyden jar we will discharge it, producing a spark, and if we so arrange as to bring the connecting terminals over the mouth of the bottle the mixed gas will ignite with an explosion, which will be loudest when the proportions of the two gases, hydrogen and oxygen, are about two measures by volume of the former and five of the latter. Immediately after the explosion the bottle will again fill with air, to be again mixed with the hydrogen which is being constantly set free by the decomposition of the water, and the experiment may be repeated at short intervals until the acid is weakened or the zinc exhausted.

75. For the purpose of testing the presence of electricity a simple piece of apparatus called a proof plane is essential, and consists of a small disc of gilt paper the size of a half dollar attached to a thin stick of shellac or a wooden handle which has been thoroughly coated with shellac varnish. With this, by touching a charged body, we can take from it a portion of its charge. This simple piece of apparatus enables us to show that all portions of a charged body may not have the same density of charge. The proof plane for the time being, while in contact with the body, is virtually a portion of that body. Roughly, the comparative densities of two charged surfaces may be shown by the electroscope, but for more accurate measurements, an expensive and delicate piece of apparatus called Conlomb's Torsion balance is required. The instrument is named for its inventor, and depends on the principle

that the torsion of a wire is proportional to the repulsive force of two similarly charged bodies, one of which is a fine shellac needle fixed on the wire, and carries a small pith ball, and the other a proof plane. After the two have been in contact, repulsion follows and twists the wire. A delicate scale shows the amount of torsion.

76. The density of electricity residing on the surface of a conductor sufficiently removed from bodies affecting it as to be uninfluenced by them, is materially dependent as to distribution, on the shape of the charged body. For instance, a perfect metallic sphere shows the same electrical density over all portions of its surface, and while the charge of a metallic disc is hardly appreciable on the two surfaces, yet close to the edges it increases rapidly to the outer limit of the body.

77. This density increases at all pointed as well as rounded extremities. The density is greatest on the most projecting parts of the surface, or those which have the sharpest convexity, while hollows and indentations show little or no charge. In consequence of this strain at a sharp projection on a charged conductor, or still more markedly, at a point, as in a sharpened wire, the condensation of such an amount of force within such restrained limits produces a very rapid escape of electricity from such points. For this reason conductors which it is desired should retain their charge should have no edges or points, and must be very smooth. This is why the terminals of leyden jars and other similar apparatus are in the form of knobs, and the combs of electrical machines are, like lightning rods, pointed, to facilitate silent, rapid leaking.

78. In general the loss of charge when an insulated, charged conductor is left, is mostly through dampness of the surrounding air, but there is a second cause which is known as convection. (72) A layer of air next the electrified body, being in contact with it, is charged and then repelled. As the air is in constant motion, this portion of the charge is lost and a second layer of air repeats the subtraction, and so on, until

there is none left. Dust in the air also weakens a charge by dividing it in like manner, being attracted—charged—repelled successively, and occasionally adhering, thus forming a point which still farther exaggerates the dissipation.

*Experiment 1.* If on the terminal of an electrical machine we erect a pointed wire, and bend the upper portion to a horizontal, on turning the handle of the machine, the electricity

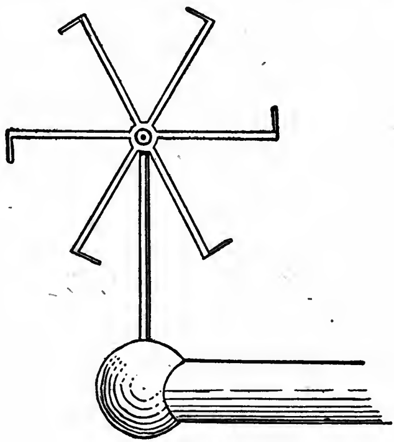


Fig. 5.

ELECTRICAL REPULSION.

will flow silently from the point, in accordance with the statement just made in explaining convection. This wind, the result of repulsion, is often sufficient to show a marked effect on the flame of a candle. The experiment may be farther elaborated if upon an upright wire on the terminal, a set of horizontal pointed wire spokes projecting from a hub, be balanced. and the outer ends of these be all bent horizontally at right angles to their former direction; if they all point in the same

direction, and move readily, the mutual repulsion between the electricity on the point and the electricity with which it has parted to the air, being of the same sign, will cause the little skeleton wheel to revolve by repulsion. A perpendicular arrangement may accomplish the same results. Fig. 5.

*Ex. 2.* When an electrical machine is actuated in the dark, accompanying the slight crackling which indicates leaking, at several points on the frame may be seen luminous appearances, called brushes; and if a conductor, a wire, or the hand, be presented toward the terminal of the machine, just beyond the striking distance of a spark, one of these brushes will reach for the object so presented. The brush discharge consists of a short stalk, from which spreads a shape not unlike a palm leaf fan, consisting of rays which become thinner and lighter towards their outer extremity.

*Ex. 3.* If a doll's head having hair, be placed on the terminal of the machine, and the machine actuated, the hair will tend to straighten out in all directions, and will reach for the hand or other conductor presented. Discharging the machine by placing its terminals in contact, will restore the hair to its normal condition.

*Ex. 4.* A human leyden jar may be made by a person occupying a stool or chair, the legs of which are standing in dry India rubber overshoes, in tumblers, or in telegraph insulators. In this position the human leyden jar is capable of being charged, and of giving shocks to parties standing on the floor or ground. The hair of the human jar will stand on end if the charge is considerable, and be attracted by the approach of any conductor. The charge may be silently discharged through a fork or needle held in the hand.

*Ex. 5.* Attach a rod or heavy wire to the terminal of the machine, having the curved shape of a shower bath standard, and terminating in a metal band, the lower edge of which is

fitted with points like an inverted crown. One sitting or standing beneath such an attachment will feel a very perceptible and invigorating breeze.

*Ex. 6.* Approach a charged leyden jar with a sharp needle held in the hand, and the discharge will be noiseless and not unpleasant. If in a darkened room, the discharge will be seen to resemble a blue flame.

## CHAPTER IV.

### STATIC ELECTRICITY (CONTINUED).

79. In 33 it was explained that the purpose of joining the alternate sheets of a tin foil condenser with the two terminals was simply to increase the surface capacity—to conveniently aggregate the sheets into two of greater size and hence greater capacity. The same result may be attained with a number of leyden jars, by placing these upon a sheet of tin or other metal, and connecting the upper terminals of the rods together with a wire. The metal on which the jars stand will serve to connect all the outer coatings as of one jar, while the wire will serve the same purpose for the internal coatings. The discharge from a machine or a belt may be received by any one of the jars, for each is only part of the whole. Again the jars may be insulated from the stand and so arranged that the inside of the first jar will be the receiver from the machine or other source. The outer coating of this jar is connected to the inner coating of the second jar, and the outer coating of this to the inner coating of the third, and so on through the series, the last outside coating being connected to ground. The first of these groupings very materially increases the capacity of the combination, and is called a parallel or quantity grouping. The second is known as a cascade or series grouping, and is of little importance. There being a leak at every jar the sum of this loss is the loss of one jar multiplied by the number of jars in the series; so that the sum of accumulated charges is only that of a single jar used alone.

80. While much of the apparatus suggested in these pages

is only intended for simple or temporary experimenting, and as economical substitutes for more expensive and perfect appliances, which may perhaps be beyond the reach of those for whom the work is intended, the fact must not be overlooked that a higher degree of success would result from the use of the more costly apparatus.

81. For instance, in the manufacture of glass there are ingredients used in some kinds of ware which are wanting in others, and the cheaper grades are of less value for electrical purposes than the more expensive ones. A leyden jar, to approach nearest to electrical perfection should be of glass containing no lead or other conducting material; yet for simple, cheap, experimenting, bottle glass, which stands about the lowest in such a scale, is passable. In all cases such a jar will be much improved if well varnished with shellac, and thoroughly dried before being coated. It should be entirely free from dust, as well as dry.

Fig. 6.
DISSECTED JAR.

82. The theory of the leyden jar is explained preferably through the aid of an experiment which requires a peculiar form of jar, but which is quite easily constructed.

*Experiment 1.* Take a wide-mouthed jar, which had been previously varnished, and so arrange it as that the coatings, both inner and outer, may be easily removed. Attach a ball of crumpled tin foil refuse to the lower end of the rod, low enough to lie on the bottom of the jar, which will thus form its inner coating. For the outer coating a piece of sheet metal or foil may be wrapped round the jar

and tied on, and the jar may now be charged and placed on a board or stand resting on tumblers or insulators. Now lift out the rod—being careful not to come within striking distance of the outer coating—and afterward lift the jar from the other coating. In each of these contacts a slight but not unpleasant spark will be received by the hand. Having discharged both coatings in this way, replace them, one at a time, and then discharge the jar by making contact between the two coatings, and it will be seen that nearly as much electricity will be exhibited as if the coatings had not been disturbed. This experiment, illustrated in Fig. 6, is one of Franklin's.

83. From what we have now learned we may reasonably assume that the charge of the jar lies in the glass—at least the greater portion of it—and not in the coatings, and reasoning from analogy, we may assert that the dielectric is always the seat of charge, while the conductors are merely its limiting surfaces. We may then conclude that the electrifying power of the electric source is exerted upon two dielectrics, the glass of the jar on one hand, and the air surrounding it, on the other; each of which has for its external limit the zero line of the earth, reached through surrounding objects. The action of the charge on the air through the inside coating is similar to what we find in all cases of charged bodies. The limits of this action through the glass are the inside surfaces of the two coatings. The glass jar is a solid, thin, and good dielectric, and since the thicker layer of air is more difficult to polarize, the charging power of the machine is exerted more on the glass and less on the air. Assuming that this is true, we now see why the spark in removing the inner coating of the jar in Experiment 1, under 82, was so slight. This partial discharge may be repeated until the residual charge is virtually nothing, by alternately touching the knob and the outer coatings, while the jar remains on the insulating support.

**84.** Having discharged a leyden jar by connecting its two

coatings, after a short interval a second disruptive spark, much more feeble than the first, will indicate the discharge of what is known as the remaining or residual charge. This is believed to be due to electric absorption—a capacity residing in a dielectric for absorbing a certain amount of charge, which it does not instantaneously give out. This faculty exists in all solid dielectrics, but—probably owing to the mobility of the particles—not in air.

85. The striking distance of a spark is largely a matter of potential. This faculty may be increased by turns of the machine. In practice it is shown that where two jars, one having twice the surface of the other, are charged by an equal number of turns of the machine, the larger will have but half the striking distance of the former, and that twice the number of turns are required for the charging of the larger to give it the same length of spark ; and by taking two jars of the same size, one of which is charged by a given number of turns, and the charge is then divided by bringing their knobs together, it is found on discharging the double jar that the spark is only half the length, which the single jar would give. The quantity remained the same, but the potential was halved.

86. There is then a strain or pressure between the surfaces of a leyden jar, which is greater in proportion to the increased charge. There are two directions through which an equilibrium may be accomplished by relieving this strain. The more readily arrived at is by connecting the terminals of the jar, when the resistance of the air usually breaks down, while the discharge tongs are yet at a considerable distance away from the knob. The other is through the thinner, but more resisting dielectric, the glass itself, by puncturing it.

87. A heavy disruptive discharge is not instantaneous. This is shown to be a necessity of the case, it having been demonstrated that all such discharges are made up of a great number of oscillatory, or alternate discharges in opposite directions.

This action has been attributed to the result of suddenly striking the air, which is elastic, a quick, powerful blow, which produces a bouncing like the vibrations of a drum head. The discharge, if sufficiently long, assumes the brush form, near its close. The charge in some respects resembles the action of water when this is suddenly allowed to escape confinement into a receiving vessel. There is a surging action back and forth, growing less with each successive movement, until the mass becomes quiet. The action of a swing is also illustrative of this oscillatory discharge. It has a pendulum like movement which grows gradually less until overcome by gravity. The rapidity of the discharge, despite these back and forth movements is such that, if a disruptive spark is thrown into a quantity of gunpowder it will not be ignited ; but if the speed of the spark is reduced, by causing it to pass down a dampened string, it will explode it. In the former case it moved too quickly to produce the heat required for the purpose.

88. Two experiments compared will show the results of rapid and slow discharges.

*Experiment 1.* Take a round cardboard arranged to revolve upon its center. Divide its face, so as to have several alternate sectors of white and black covering it. Now, revolve this rapidly, and while it is in motion in a darkened room a spark from a machine will illuminate it so nearly instantaneously as to show the markings on the disc as plainly as if it were at rest. The instantaneous view of it is held by the optic nerve long enough to make a perceptible impression. Fig. 7.

*Ex. 2.* Hold the knob of a charged leyden jar on the centre of a shellac plate that has been excited by being rubbed with flannel, having previously been very lightly covered with a mixture of powdered vermillion and lycopodium, dusted on through fine muslin. The two powders will separate and form concentric rings around the central knob.

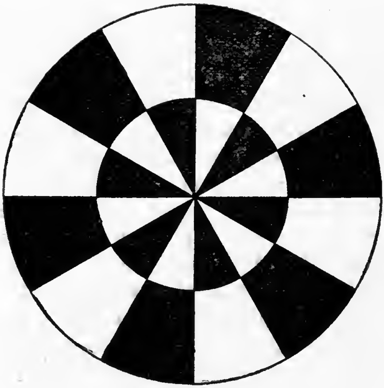


**Fig. 7.**

DURATION OF SPARKS.

*Ex. 3.* A variation of the last. With the ball of a charged leyden jar trace a design on a plate of hard rubber or shellac. Place the jar on an insulated stand in order to transfer the hand from the inner to the outer contact without getting a shock. Then with the outer coating of the jar trace another pattern on the cake. You now have charged different portions of the receiving cake with the two electrical conditions. Dried sulphur and red lead powders, well mixed, are next dusted over the plate through fine muslin. These powders now, having been electrified oppositely by the friction of mixing, will each seek its opposite on the plate. The — sulphur will seek the + and the + red lead will seek the — charges received from the inner and outer coatings, respectively. These two experiments are the invention of a German philosopher of the last century, whose name they bear. Lichtenberg's dust figures, Fig. 8.

89. The nearer the two poles of a condenser are brought together the greater will be the attractive power which tends to bring the two electrical conditions in contact and to equalize them ; and hence the greater will be the condenser's capacity. The sheets of mica or paraffined paper separating the tin foil in a condenser, are hence best when thinnest, and when the sheets are pressed closely together. The leyden jar which, other things being equal, is constructed of the thinnest glass, has a

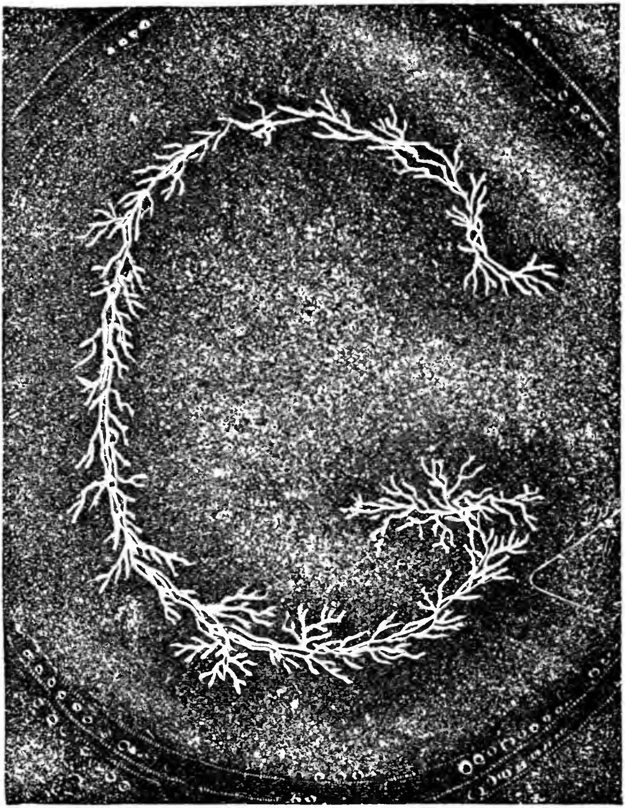


Fig. 8.

DUST FIGURES.

greater capacity than a thicker one, but if of too thin material it may be destroyed by a powerful charge, the spark of which will pierce a hole through it in its effort to reach the opposite electrical condition, on the other coating of the jar. This may usually be prevented by making a permanent contact from the foil inside the jar to the central rod, by some metallic substance—foil or wire.

90. This disposition to escape across a dielectric or non-conductor through which induction is possible, is known as a stress; the pressure or force or mutual attraction which develops the strain or change of form or volume in the dielectric. "If a leyden jar is made of thin glass it may give way under the stress; and when a leyden jar is discharged the layer of air between the knob of the jar and the knob of the discharging tongs is more and more strained as they are approached towards one another, till at last the stress becomes too great, and the layer of air gives way, and is 'perforated' by the spark that discharges itself across. The existence of such stresses enables us to understand the residual charge of leyden jars, in which the glass does not recover itself all at once, by reason of its viscosity, from the strain to which it has been subjected. . . . Electric force acts across space in consequence of the transmission of stresses and strains in the medium with which space is filled. In every case we store not electricity but *energy*. Work is done in pushing electricity from one place to another against the forces which tend to oppose the movement. The charging of a leyden jar may be likened to the operation of bending a spring or to pumping up water from a low level to a high one. In charging a jar we pump exactly as much electricity out of the negative side as we pump into the positive side, and we spend energy in so doing. It is this stored energy which afterward reappears in the discharge."—*Thompson.*

91. There are then three conditions which affect the capacity of any condenser:

*a.* The extent of surface of the metallic portion;

*b.* The thinness of the separating dielectric;

*c.* The excellence of the dielectric; or, its capacity.

92. The length of the electric spark is dependent upon:

*a.* The potential difference between the discharging terminals;

*b.* The character of the medium which separates them;

*c.* The density of that medium;

*d.* The kind of material forming the electrodes or discharging terminals;

*e.* The shape of the charged terminal; and

*f.* The direction of the discharge.

93. The passage of a spark, then, is assumed to be preceded by a heavy stress which affects all the particles of air in its course, and which breaks down at the instant of discharge, the spark overcoming the resistance offered by the particles. If the distance separating the terminals is comparatively short, the spark is direct and without ramifications. On the contrary, if of considerable length it may assume an appearance like that shown in Fig. 9. The zigzag appearance is assumed to be caused by the presence of particles in the air which, through their conductivity, make a crooked path easier than a straight one. "The direction of these branches is always from the + to the — electrode." —*Thompson.*

94. The appearance of a spark discharge is that of a line of fire, while we know it is only a spark. Its appearance is an optical illusion, based on the fact that an impression on the eye lasts for a definite length of time, before it is extinguished—about one-tenth of a second (87). The spokes in a rapidly moving wheel appear to be almost solid; yet rapidly winking the eyes will enable one to see the separate spokes, because part of the impressions are cut off by closing the eyes. The same result may be arrived at by looking through one wheel at

the opposite wheel on the other axle of a rapidly moving buggy. The interrupting spokes of the one wheel prevents one's seeing all the spokes of the other, as they pass, and the view of those which are seen remain on the retina long enough to make a visual impression. The bolt of lightning which appears a streak of fire is a huge ball of electricity, and photographs have been taken which plainly show the round character of the spark.

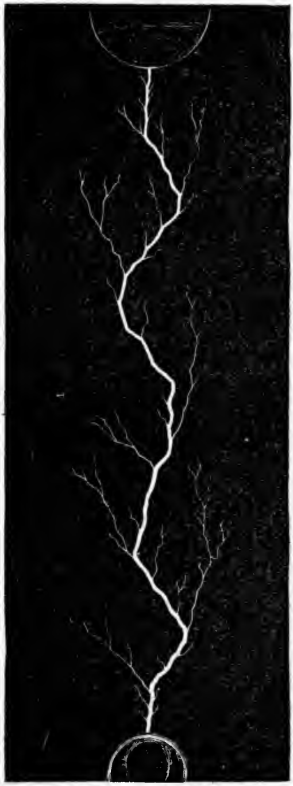


Fig. 9.
SPARK WITH BRANCHES.

95. Taking advantage of the fact that visual impressions are lasting, Wheatstone invented a very ingenious method of measuring the duration of a spark from an electrical machine, which will be understood by reference to Fig. 10, in which the circle shown represents a mirror revolving on its center $c$, in the direction opposite that of the hands on a watch. Now we wiil assume that an electric spark is produced at $a$. An eye at $o$ will see the reflection of this at $a'$. If the spark were mathematically instantaneous its image would be seen at $a'$ as a point of light, regardless of the mirror's movement. On

the contrary, if it has a certain duration the image will spread from $a'$ to $a''$ while the mirror moves from $ee'$ to $tt'$, when the spark ceases, and what has been seen in the mirror will have been a line of light from $a'$ to $a''$. This image will have twice the length of the arc $et$, for the angle $ect$ at the center is equal to the angle $a\,a'a''$, at the circumference, the one triangle having greater dimensions than the other.

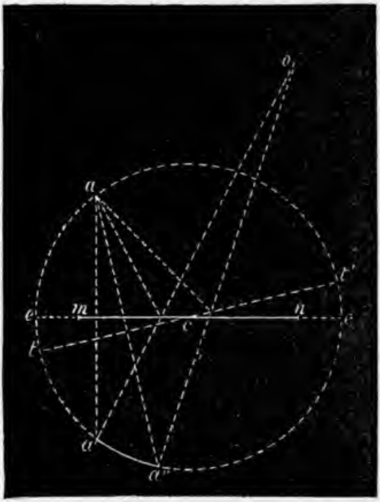


Fig. 10.
TIME LENGTH OF SPARKS.

96. In this experiment Wheatstone's mirror made 800 revolutions per second, and the observed image lasted through an arc of 24 degrees. The mirror consequently passed through 12 degrees, or $\frac{1}{30}$ of a complete revolution of 360 degrees. Then the duration of the spark was $\frac{1}{30}$ of $\frac{1}{800}$, or $\frac{1}{24000}$ of one second of time.

97. In general the length of the spark, or the striking distance of the spark, other things being equal, is directly as the difference of potential, (92). De la Rue, with a battery of 11,000 cells could only send a spark across about ⅔ of an inch of free air. From this and other data it has been calculated that a spark one mile long would necessitate a difference of potential greater than that furnished by 1,000,000,000, Daniel or blue vitriol battery cells.

98. The spark length for the same potential difference is nearly double in hydrogen gas compared with air at the same density, while in rarefied air the spark is longer. After exhaustion to near the vacuum point, the carrying capacity of the air diminishes very materially, until a point is finally reached where a spark, unless of extremely high potential will refuse to pass. This same high resistance may be arrived at by compressing the air. It was formerly taught that an almost perfect vacuum was a perfect insulator—that no spark could be forced across it ; but a recent writer in the *Scientific American* (Prof. John Trowbridge), through the use of Planté's rheostatic machine has succeeded in developing 1,200,000 volts, with which he has sent sparks through the most perfect vacuum he can produce. With this voltage he sends a spark 48 to 50 inches in length through dry air. He says: "It now becomes an interesting question whether there exists mechanical or chemical means by which a so-called vacuum can be produced which will resist such discharges."

99. An electric spark is capable of producing chemical action. Faraday showed by experiment, that however developed, or from what source, electricity is ever capable of producing the same chemical results.

*Experiment 1.* "Moisten a piece of white blotting paper with a solution of iodide of potassium. Through this send a spark and a resulting brown patch will show where the spark has affected a chemical change and liberated the iodine."—*Thompson.*

100. Cavendish has shown that a stream of sparks passed through moist air in a closed vessel, develops nitric acid, produced by the chemical union of the nitrogen and oxygen of the air.

101. The development of a modified form of oxygen gas —ozone—is another chemical result of electrical action. The characteristic smell of ozone is familiar to the employés of electric light stations.

102. The color of a spark varies with the nature of the electrodes between which it passes. This is caused by the carrying away of a minute quantity of the metal in a volatilized form. Silver and copper tint the spark a greenish hue, while iron colors it reddish. So too the color is varied by passing the spark through different gases in tubes. In nitrogen the hues are violet around the kathode, or — electrode; the rest of the light is rosy tinted. In hydrogen the discharge has a bluish hue, except where the tube is narrow, when it lights up with a clean, handsome crimson. Tubes for this form of experiment are commonly known as Geissler tubes, and are made in a great variety of twisted forms. The gases in them are partially exhausted, and the effects are made exceedingly varied and beautiful by forming them of glass containing uranium which fluoresces with a rich green light, or by making the tube double throughout part of its length, and filling the outer vessel or tube with a solution of quinine or some other fluorescent liquid. In the manufacture of these tubes a platinum wire is hermetically sealed in at each extremity, forming a metallic conductor from the outer to the inner portions of the tube, as terminals. Platinum is used for this purpose from the fact that its co-efficient of expansion by heat is so nearly that of glass that the two do not break away in cooling, which, were it to occur would be fatal to the partial vacuum required.

103. Static electricity may be produced by other means than those heretofore mentioned. Two substances struck together violently will sometimes develop opposite electrical conditions on the surfaces so struck. Volpicelli showed that by rapidly vibrating a sulphur covered metal rod the two electricities were developed at the point of contact between the conductor and the insulator; rubbing two pieces of loaf sugar together in the dark will often show sparks; quartz rock, treated similarly will show the same phenomena; and tearing paper which is lined with stiff linen, will also produce these electrical effects. All these applications of force are so nearly

allied to that which generates friction, that to consider them as identical with it requires but a slight stretch of the imagination.

104. Crystallization, the cooling of fused masses, combustion, evaporation, all show electrical effects, more or less powerful; and compression, as for instance, the pressure of cork against the metals, gutta percha, and some of the resinous gums, develops + electricity on its contact surface, while the same treatment of mineral spars, and of animal substances develops the opposite polarity. According to Péclet the degree of electrification produced by rubbing two substances together is independent of the pressure and of the size of the contacting surfaces, but depends solely on the materials and the velocity of the frictional movement. Rolling contact and sliding friction are equally efficient.

## CHAPTER V.

### ATMOSPHERIC ELECTRICITY.

105. The similarity in the effects of lightning and those of the electric spark enlisted the minds of the earliest physical investigators. Lightning ruptures and disintegrates substances opposing its passage, and where these are combustible, often ignites them. It is capable of producing all the effects of heat in subduing the most obdurate metals, and volatilizing them, and leaves behind it, in many instances, the odor which we recognize as that pertaining to ozone. To Franklin is given the credit of thoroughly identifying the phenomena—of proving experimentally with his historic kite, and the aid of leyden jars, that, save in the factors of quantity and intensity, the two were one.

106. A French experimenter—Dalibard—acting on a suggestion from the American philosopher, erected an iron rod above a house near Paris. From this he drew electricity during thunderstorms and experimented with electrical apparatus. These experiments produced the wildest enthusiasm among investigators, and careless handling of the dangerous element led to painful, and sometimes quite serious accidents. Franklin, himself, in attempting to kill a bird with the spark, to use his own language, "came very near killing a goose," while Richmann, of St. Petersburg, was instantly killed by a spark from a rod erected in imitation of Dalibard's.

107. Franklin enumerated the following specific characteristics pertaining to, and tending to unify the two phenomena of static electricity: "Giving light; color of the light; crooked direction; swift motion; being conducted by metals; noise in exploding; conductivity in water and ice; rending imperfect conductors; destroying animals; melting metals; firing inflammable substances; sulphureous smell [ozone]; and similarity of appearance between the brush discharge from the tips of masts and spars sometimes seen at sea, called St. Elmo's fire by the sailors, and the slow escape from points on an electrical machine or a leyden jar." He had also noticed that both the electric spark and the lightning spark were capable of developing magnetism in steel needles.

108. Of the origin or cause of atmospheric electricity there is want of unanimity of opinion among scientists. It has been variously ascribed to the condensation of vapor; to the friction of wind; the evaporation of water; induction from the sun; the motion of bodies in the earth's magnetic field of attraction; combustion; varying and unequal temperatures, which are constantly changing.

109. This, however, is quite generally accepted as true, as to the enormous potential of atmospheric electricity which discharges sparks through miles of one of the best non-conductors known: that it is to the condensation of the watery vapors of the atmosphere that this high potential difference is due.

110. The theory of thunderstorms is thus given: Solids and liquids cannot be charged through their substance; if charged at all the electrification is upon their surface. But gases and vapors, bein composed of myriads of separate particles, can receive a bodily charge. The air in a room in which an electric machine is worked is found afterward to be charged. The clouds are usually charged more or less with electricity, derived probably from evaporation going on at the earth's surface. The minute particles of water floating in the

air gradually become more and more highly charged. As these fall by gravitation and unite together, the strength of their charges increases. Suppose eight small drops unite in one. That one will have eight times the quantity of electricity distributed over the surface of a single sphere of twice the radius (and therefore of twice the capacity) of the original drops; and hence its electrical potential will be four times as great. Now a mass of clouds may consist of such charged globules, and its potential may gradually rise, therefore, by the aggregation of drops and the electrification at the lower surface of the cloud will become greater, the surface of the earth beneath acting as a condensing plate, and becoming charged by influence with the opposite electrical condition. Presently the difference of potential becomes so great that the intervening strata of air [the dielectric] give way under the strain, and a disruptive discharge takes place at the point where the air offers least resistance. This spark, which may be more than a mile in length, discharges only the electricity which has been accumulating at the surface of the cloud, and the other parts of the cloud will now react on the discharged portion, producing internal attractions and internal discharges. The internal actions thus set up will account for the usual appearance of a thunder cloud, that it is a well-defined flat-bottomed mass of cloud, which appears to be boiling or heaving up with continual movements.—*Thompson.*

111. The formation of hail, a phenomenon which is not well understood, is now supposed to be a cause, rather than a result of electricity. A hailstorm usually occurs in the hottest part of the day, in the sultriest season, and these storms are most severe in the tropics. A popular belief has attributed the formation of hailstones to electrical action. A daring experiment by a French balloonist perhaps tended to confirm this theory. He ascended into the clouds during a severe commotion of the elements, and witnessed the growth of the hailstones, as they

played between the +ly and —ly charged clouds until gravity overcame the attraction and they fell to the ground. It is probable that in the meeting of two clouds of widely differing temperatures, the warmer being moisture laden, the moisture is condensed into drops, and this condensation produces a rapid fall of temperature to below the freezing point. The nucleus being formed it is possible the growth may be explained as stated by the experimenter mentioned.

112. Arago classified lightning under three divisions. 1. Zigzag or forked lightning, which includes the ordinary form, usually accompanied by a more or less distinct report, sometimes prolonged into a heavy, rolling sound. This form may result from a disruptive discharge from the earth to the clouds, from clouds to earth, or from one cloud to another. The discharge is from the +ly to the —ly charged body. 2. Sheet lightning or heat lightning, sometimes called summer lightning, which is assumed to be the reflection from discharges so far away as to be invisible to the observer. 3. Ball, or spherical lightning, a rare and peculiar variety, consisting of a ball of electricity, which sometimes performs curious antics, such as bouncing over a surface on which it strikes, like an elastic ball, then, with no apparent reason, exploding with much force and a loud report.

113. Attending violent discharges of terrestrial electricity various forms of thunder are usually heard. Sometimes these are long, rolling sounds, as from a ball tumbling down a series of inclines, now loud, now low, with indistinct muttering noises; and again the original clap or burst seems repeated, as by echoes, gradually growing fainter until exhausted. If the discharge is near the listener, a sharp, hissing sound, not unlike that of burning grease, but far louder, precedes the stroke so short a time as to seem part of the discharge.

114. Formerly this rolling or echoing, the reverberation of whatever nature, was disposed of by generalizing it as echoes

from the surrounding clouds. The length of the discharge is probably responsible for much of the sound produced. We know that a short spark from a machine or a jar is straight, and the noise accompanying it is a well defined short snap; while the long, branching spark has a much longer, and a different sound. Now in a short, straight path a lightning stroke has a short, sharp clap (a snap magnified), and when we see a long, forked or zigzag discharge we get a greater or less snap from every branch, on its way from the + to the — electrode, which is taken up by the clouds, and hurled back in the form of rattle or roll, as an echo, which is undoubtedly responsible for a portion of the sound disturbance, while the heating of the air, expanding it suddenly and reducing its volume by consuming its oxygen, thus forming a comparative vacuum and allowing the surrounding air to suddenly close up the gap thus formed, produces a commotion which could not well occur without creating a marked sound disturbance. The hissing sound is probably caused by the convective discharge of the approaching bolt of, say + electricity, forcing back the similar electrical condition, and attracting to itself the opposite or — electricity. This effect is virtually instantaneous, and the discharge is similar in manner to the escaping electricity, as explained in the experiment, Electrical Wind (78 Ex. 1).

115. Again, there is no doubt that the discharges under consideration are usually, if not always, of an oscillatory character, and these vibrations are exceedingly rapid, as the entire flash has been found to have a duration of but a small fraction of a second—according to Wheatstone $\frac{1}{24000}$, in the case of a jar spark (95), and according to other authorities, less than $\frac{1}{100000}$ in the case of lightning discharges—these oscillations are of themselves sufficiently rapid to produce a very high and penetrating sound. This would be too rapid for the human ear to take cognizance of, as the ears of mankind recognize no sounds produced by vibrations exceeding 40,000 per second.

Now, it may be possible that these excessively rapid vibrations become retarded in their rate, by reason of the cause traveling away from the listener; just as the tone of a receding locomotive bell on a moving train runs down the scale. In any event, one theory is good until another displaces it; these are all theories.

116. We have seen how the disruptive discharge from a jar is capable of mechanical disturbances. The same faculty is markedly perceptible in lightning discharges; quite often despite the most careful precautions in the way of rods. In a subsequent chapter the subject of rods will be given more extended attention. It is not unusual during a heavy thunder shower, when every surface is thoroughly dripping with water, for a building to be literally torn asunder by a single stroke. An instance which is well authenticated will illustrate this. During a very severe spring shower, accompanied by most terrific and brilliant thunder and lightning effects, a court house not more than a quarter of a mile from the narrator, was struck. There was no rod upon the building, but above the dome a bar of iron an inch and a quarter square was made the support of a gilded wooden ball, the rod finishing above it in a point. There was very little of the ball ever found after the stroke. The roof was flowing with water, so that the gutters were incapable of carrying off half of it, and the down spouts, six inches in diameter were running full. Yet despite all this conducting capacity, some portion of the charge went down through the belfry into the dry timbers beneath the roof, thence down dry rafters to the plate, splitting them into kindling wood, and finally bursting through an 8-inch brick wall to the tin down spout, out through the bottom of this, blistering it, and through the wooden trough beneath this into the ground, making a hole two and a half inches through the trough. The chips made all indicated that the charge went downward, as they were below the hole.

117. On the opposite side of the street from the building there stood a small elm tree, just budding, which was evidently struck from an opposite direction—upward. The bark of the trunk was broken off near the ground, and stripped upward, while nearly every bud was burst open by the outgoing rush of electricity. This impulse, usually called the return charge, is undoubtedly the result of attractive strain set up by the immense downpour of the cloud discharge; or it may be the repulsive action occasioned by the sudden surcharge of the earth in the neighborhood of the stroke. In the first instance the upward burst would be of the opposite polarity, and in the second of the same polarity as the lightning.

118. Remember that in all cases where a charged cloud hovers over the earth, a strain is set up, varying in direct proportion to the heaviness of the charge and the thinness of the dielectric air separating it from the earth, the combination of cloud, air and earth representing, on a huge scale, the leyden jar or other condenser. If the cloud is charged with positive electricity, then the positive and negative electricity of that portion of the earth within the influence of the cloud, are separated; + electricity is driven away, or repulsed, and — electricity is attracted.

119. There is a form of lightning discharge which is quite rare, and appears to be made up of a rapid succession of detached globules or sparks, and commonly known as bead lightning. On a much enlarged scale these beads become balls of fire, and behave in such a grotesque manner at times that they have been called the acrobats of electricity. This is Arago's third form of lightning (112).

120. The rare appearance of these globular exhibitions has caused the accounts of their existence to be more or less doubted, and chroniclers have been strongly suspected of romancing when describing them. Their existence is no longer

to be doubted, since they have been reproduced on a small scale and witnesses of undoubted veracity, including well-known scientists, have testified to having seen them in nature.

121. Over half a century ago, Noad, a well-known electrician, experimenting with a partially exhausted tube saw a ball of fire leave one terminal and proceed leisurely to the other terminal. It was an accident and he was unable to repeat it. A station agent on the Paris and Rouen railway during a storm, saw a ball of fire come slowly toward the telegraph wire, and disappear noiselessly ; but the telegraph instruments (the needle system) were completely ruined temporarily.

122. Gaston Planté, the original inventor of the storage battery, investigated the circumstances connected with a storm which occurred on the 24th of July, 1876, covering the ground with hailstones of unusual size, and deluging the place de la Bastile, Paris. Ball lighting was seen at three different points in the city. The manager of the Theatre Beau Marchais saw a ball of fire descend from a cloud, brush past a potted plant in a window, fall to the ground and disappear. A second party saw three, and a third saw similar phenomena, which fell into the water with which the court was flooded by a veritable water spout.

123. It is not necessary to cross the ocean, however, to record instances. Some years since one of these erratic varieties visited a fine residence in the south division of Chicago. The family of a well-known resident had just left the lawn and retired into the house because of the approach of a threatening cloud, when one of the family called attention to a ball of fire moving at a very moderate speed along the gilt picture rail. Arriving at the corner of the room it left the rail and went outside, making a way for itself through the brick wall, with a heavy explosion.

124. M. Planté, after long and careful experimenting to reproduce the phenomena of globular electricity, gave the world the following: "If the positive wire of a battery of 200 cells be connected to a fluid voltameter containing a solution of sulphuric acid, or of common salt, and we now bring the negative terminal to the surface of the solution, this surface contact will tend to cause volatilization or fusion of the metal. This action will be accompanied by a species of explosion and a parti-colored flame, governed in its hue by the nature of the metal of the electrode. Now, by weakening the strength of the voltameter solution, to prevent fusing the metal, we may produce a series of sparks, of gradually decreasing intensity, accompanied by slight, crackling noises.

"If, on the other hand, reversing the experiment, we insert the negative terminal, and bring the positive to the surface of the fluid, we will see at this point of contact a luminous liquid

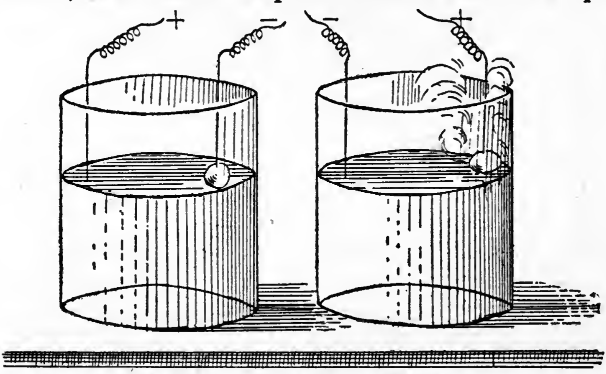



Fig. 11. Fig. 12.

PLANTE—REPRODUCTION OF GLOBULAR ELECTRICITY.

globule, accompanied by a peculiar rustling sound. Now, withdraw this wire a trifle, so as almost to sunder the circuit, and the globule will augment in size to about one millimeter

[about $\frac{4}{100}$ of an inch] diameter, at the same time clinging to the wire as if by attraction, and assuming a gyratory movement. Its rapid rotation now changes its form to that of an oblate spheroid, the diameter at the equator constantly increasing as the poles flatten until it finally disappears with a snap and spark at the negative terminal. It will re-form again and again to be extinguished in like manner." Figs. 11 and 12.

125. This gyratory movement is not always, according to Planté, in the same direction. "It may be either with or against the clock hands movement, because it is the result of escaping energy which by reaction, as in the case of the electric whirl (78), causes it to move; and the least variation right or left, in the point of contact of the little sphere and the surface of the fluid may change the direction of the rotation, the

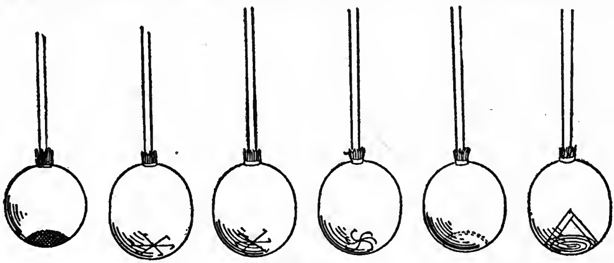


Fig. 13.

VARIOUS FORMS OF PLANTÉ'S GLOBULAR ELECTRICITY.

contact surface being only a point. The luminous appearance is due to the converted energy at the point of contact, and the hissing sound results from the condensation of steam particles developed by the heat evolved."

126. The intermittent action and a spark which shows at the negative terminal are thus explained. Being but slightly immersed in the liquid the combined electrical and capillary attraction tend to form the drop of liquid, and break the current, by lifting this away from the solution. The drop now

falls back, and completes the circuit, the spark is discharged, the circuit recompletes itself, and the phenomena is repeated. The drop thus enacts the part of a "buzzer" or interrupter, each break revealing a spark, each contact resulting in a break.

127. The aggregation of fluid at the terminal M. Planté explains as the result of the flow of energy from that point. He instances a still more striking effect, by using a current of higher tension and surrounding the electrode with a glass tube. Here the liquid, having but a limited space, naturally aggregates under the least confine possible, and assumes the spheroidal or globular form, the form which fluids assume on highly heated polished surfaces—as water on a hot, smooth stove—the natural form of all fluids in space.

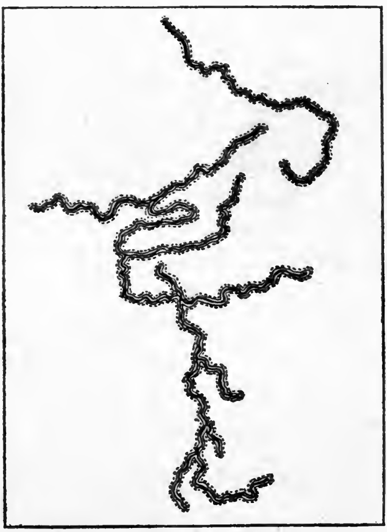


Fig. 14.

PLANTE'S ELECTRIC CHAPLET.

128. "With a battery of 800 cells, and a liquid voltameter charged with distilled water, the positive pole being immersed," to quote Planté, "I exhibited a yellowish flame about two centimeters in diameter, nearly spherical, while the platinum wire was heated to nearly the fusing point, from 14 to 15 millimeters above the fluid. This flame is formed by the rarefied, incan-

descent air, the vapor of the metal of the electrode and elements of the decomposed water."

128 *a*. "Diminishing the intensity of the current, by introducing a water resistance, to avoid fusing the electrode, the light now appeared in the form of a small globe of fire from 8 to 10 millimeters in diameter; and if now I raised the electrode a trifle from the liquid the globe assumed an ovoid form. Luminous blue points, constantly varying in number arranged themselves in concentric circles at the surface of the water, and rays of the same color shot out from the center, meeting these points. At times these assumed rotary movements, now right, now left, without apparent reason. Again, a portion of these disappeared from one side of the circle, and curves, variously disposed, were traced by those remaining. When the gyratory movement materially increased, the rays disappeared entirely, and only blue, concentric circles remained." Fig. 13.

128 *b*. These luminous points are the issuing points of convective discharge, and the gyratory motion is amenable to the causes mentioned above—reaction due to escaping energy.

128 *c*. "When the electrode is positive the spark still assumes the ovoid form, but is penetrated by a cone of violet colored light. Under the conditions last mentioned the spark manifests itself at about one millimeter above the liquid surface."

129. A very ingenious experiment, due to the late Count du Moncel, illustrates quite perfectly the "perambulating" of spherical electricity: "In place of fixing the electrode permanently at the surface of the liquid, as hitherto shown, we [Du Moncel & Planté] suspend the wire from the ceiling or some higher point, thus giving it the form and action of a pendulum, being sure to give it length sufficient to allow for considerable movement at the lower extremity, without breaking too far away from the surface. The lower extremity of this

being in close proximity to the fluid, will, as it gyrates, carry the luminous globe with it; and to make the illusion complete it is only necessary to perform the experiment in a dark room, where only the spark is visible."

130. Planté constructed a rheostatic machine (98), an invention which developed a high tension, constant, static discharge from condensers, these being charged as described in 79, where the inside coatings are made one pole, and the outside coatings are made the other (charging in multiple) and discharged in series, or cascade, where each jar is connected to the next, serially. With this powerful piece of apparatus Planté caused such a pellet of fire to assume the progressive movement without changing the position of either electrode. He induced a spark of this character between the mica and tin foil of a sheet condenser, which traced on the foil a deep, irregular furrow, showing the leaps made by the spark from place to place. "Nothing," says Planté, "could be more comical than the movements of this glittering little orb, solemnly marching forward, carefully selecting its route, and choosing its objective points according to the varying resistance offered by the insulating mica." The plate was cut through along the path of the fireball, and the tin foil showed a double chaplet of minute beads, fused at the edges of the destroyed insulator." See Fig. 14.

131. It is claimed by this scientist who did so much in the way of investigation, that "the presence of ponderable matter in some form, is indispensable to the production of globular electricity. That this substance, whether vapor or gas, must be an imperfect conductor, raised to incandescence by the electric discharge, and susceptible of expansion under the influence of exterior mechanical or physical force."

132. Du Moncel produced a globular discharge between two plates of glass which were covered with a film of moisture;

conditions quite similar to those in nature from which such discharges result.

133. Let us suppose that a stratum of very damp air near the earth is charged inductively by a storm cloud above it, and that between these two plates or electrodes there is a thin dielectric of comparatively dry air, more or less perfectly separating the two charged bodies. This is one of nature's condensers. The layer of drier air is of varying thickness, and hence a better insulator at some points than at others. It is easy to conceive that the electric charge generated in this moist air will reach out toward the inducing cloud, which in turn will tend to approach, and the two will thus strive to mingle and restore the disturbed equilibrium. At the border of the partial insulator the moisture-laden air will be drawn partially within a drier stratum, and may be surrounded, cut off, and separated from the parent source by a change in the shape of the insulating air. The action of surrounding attractions will now expand this enveloped and charged mass, as shown experimentally by du Moncel and Planté. The natural sequence of this isolated and expanded charge will be its assumption of a spherical form, and the taking on of a rotary motion.

134. The atmosphere surrounding the earth is seldom, if ever, entirely free from electricity. The various causes which are supposed to excite electrical conditions, such as have been mentioned (108), are, one or more of them, constantly active. Evaporation, condensation, thermal changes, and other disturbances will produce changes in the electrical conditions, so that we may have more or less intense action, or may find either the positive or negative condition; and both these characteristics may change at any time with a change in the exciting causes.

135. Certain facts however are quite generally conceded, which are:

(*a*) When the sky is free from clouds the atmosphere is always positively charged, and its potential rises rapidly as we ascend from the earth. Becquerel proved this experimentally in an ingenious manner, on Mt. St. Bernard. He covered a silk thread with tinsel, and insulated this with oiled silk. One end of the metal-covered thread was connected to an electroscope while the other was attached to a metal pointed arrow. Shooting this arrow horizontally provoked no disturbance between the straws of the electroscope; but when shot into the air they diverged as the arrow rose, and stood widest apart when the arrow pulled the ring away from the instrument, leaving it charged. A delicate electroscope will show the same fact, when its perpendicular altitude is changed.

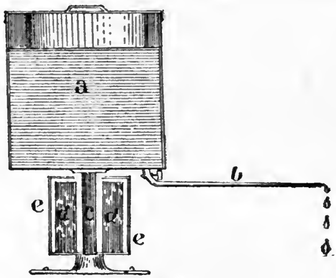


Fig. 15.

LORD KELVIN'S WATER-DROPPING COLLECTOR.

(*b*) This electrical condition is often changed to the reverse or negative, by the approach of dampness in the form of mists, fogs, etc. In stormy, wet weather, the condition is more usually negative, but sometimes changes many times in twenty-four hours. According to some authorities many times in one hour.

(*c*) It is found to be stronger when the elements are at rest than during atmospheric commotion. During a wind there are different electrical conditions being moved through the atmosphere, and these, as has been suggested, may serve to equalize the potentials which would otherwise show in excess.

(*d*) There are daily periodical variations, occuring as follows: The first maximum is found directly after sunrise, the

second shortly after sundown. The first minimum occurs just before sunrise, the second during the afternoon, at the hottest part of the day.

(*e*) A yearly variation has also been assumed with a maximum in winter. According to Quetelet "the atmospheric electricity bore something like the ratio of thirteen in January to one in June."

(*f*) The electrical condition of rain, hail, snow, etc., is sometimes positive, sometimes negative. German investigators found that rain was about equally +ly and —ly affected, while snow was shown to be four times as often + as —.

136. Many ingenious methods have been devised for collecting the electricity of the atmosphere. One of these has already been mentioned. Volta employed a burning match, attached to the top of a rod which formed the terminal of a delicate electroscope. If the electricity is of the + sign its influence attracts the — electricity of the rod to its upper extremity, whence its discharge is accomplished by convection in the products of combustion of the match, and as the + electricity is forced back by repulsion, the electrometer will show the same electricity as that of the atmosphere. With a reverse electrical condition the reverse action would take place.

137. Lord Kelvin constructed an apparatus shown in Fig. 15, consisting of an insulated cistern *a*, with a drop nozzle *b*, protruding into the outer air, from which the water slowly drops, regulated by the cock. The brass can or cistern, *a*, is supported on a glass rod, *c*, surrounded by, but not in contact with pumice, shown in section *d d*. This pumice is moistened with sulphuric acid. Outside this pumice a shell of gutta percha separates it from a brass case *e e*.

138. Tapers may be burned in severe weather with the same result. In either case the electricity of similar sign to

that of the atmosphere is driven off, in the one case in the water drops, in the other through the smoke and heated air of the burning material. Such matches or tapers have been made of blotting paper, steeped in a solution of lead nitrate, which after being completely dried is rolled up in the form of matches, and may then be attached and burned at the upper extremity of a light metal rod, surmounting the upper part of the electrometer.

# Electricity Simplified.

## CHAPTER VI.

### LIGHTNING RODS.

139. When Franklin had shown by experiment that the electricity of the clouds could be brought to earth by his kite string conductor he conceived the idea of discharging the threatened blow by silently drawing it away through a gradual leak, as has been shown can be done with a charged jar through a needle (78, ex. 6). The result was the suggestion of a rod connected at its base with a good earth contact, while its upper extremity, far above the building to be protected should terminate in a sharp point, and this, to prevent rust, should be gilded. His theory was that before the film of air between the cloud and the earth became dangerously thin—in other words, before the striking distance was reached—the sharp point would silently discharge the cloud, which so closely resembled the inner coating of a leyden jar, while the earth, by induction, represented the outer coating (78).

140. Since Franklin's time it has been shown that the theory which he advanced relative to the area of protection is at variance with experience; and it has also been clearly demonstrated that in a great number of instances lightning rods have been a menace rather than a protection to the property over which they were erected.

141. The researches and experiments of Dr. Oliver Lodge, which oppose and are largely contradictory of preconceived notions, have been quite generally endorsed by advanced electricians of to-day.

142. He makes a broad distinction between:

(1) A steady strain or current.

(2) A sudden rush or oscillatory, disruptive discharge.

143. The first of these occurs when the cloud comes in the vicinity of a projecting point, whether this is from the earth or from a second cloud, and is discharged before the striking distance is reached. So far Franklin's practice was in accord with facts.

144. The impulsive rush occurs when a disruptive discharge is provoked by the sudden freeing of a charge from a neighboring cloud, which is within striking distance; and when thus overloaded the receiving cloud is capable of breaking through the dielectric layer of air between it and the earth, which it was before unable to accomplish; or when a cloud in its neighborhood which is holding its charge bound is discharged in another direction, and the inductive action which held it is suddenly withdrawn.

145. These different results are somewhat similar to those accomplished by water or some other fluid, with which one desires to fill a cup or vessel having a small neck. By slowly pouring we may fill it without overflow; but pouring suddenly from a tub or a pail will seldom accomplish the desired end.

146. In all cases of such enormous disruptive discharges there is an electromotive force set up in the rod which opposes the direct discharge, and thus, damming up the flow which must escape in some direction, causes it to fly off in lateral discharges. This fact is quite at variance with the commonly received belief that lightning follows the path of least resistance, for the air is certainly a worse conductor than the metal rod.

147. "The old 'drain-pipe' idea of conveying electricity," says McAdie, "must give way to the new proposition, based upon recent discoveries, that even draining off must be done in an appropriate way to be effective. . . . . In the past few years we have learned, through the work of Hertz and others, that when an electric current flows steadily in one direction in a cylindrical wire its intensity is the same in all parts of the wire; but if the current be of an oscillatory character, that is, a current which rapidly reverses its direction,

the condition no longer holds, and if the alternations are very rapid the interior of the wire may be almost free from current. If lightning then be a discharge of an oscillatory character, it may happen that the current flowing down the lightning rod would be only *skin* deep."

148. This fact assumed, and it is quite generally accepted as a fact that an oscillatory current fails to charge the center of a round conductor, makes it plain that surface is of paramount importance in a lightning conductor; that the same amount of metal in the form of ribbon or cable is preferable. "A sheet of copper constitutes a conductive path for the discharge from a lightning stroke much less impeded by self-induction than the same quantity of copper in a more condensed form, whether tubular or solid."—Sir Wm. Thomson (Lord Kelvin).

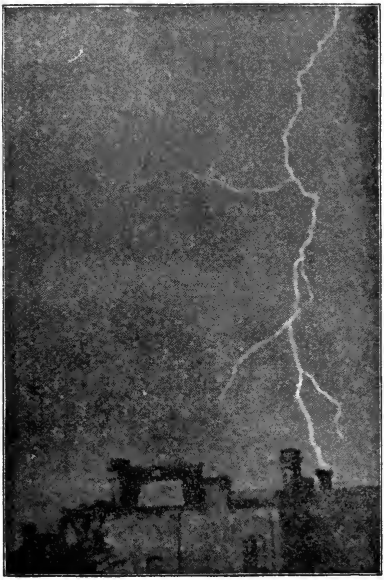


**Fig. 16.**

149. Faraday's idea of a rod was based on its volume, while opposed to him was the surface area theory of Sir W. Snow Harris, which is to-day being confirmed. In reply to the questions of an officer of the British navy relative to a lightning conductor which was to be placed

on a certain lighthouse, Faraday said, very positively, that solid rod was better than the tubular rod; that solid volume was everything, superficial area nothing. Moreover, if Harris says otherwise, "then he knows nothing whatever about it!" The solid rod was approved by the admiral, and put up. When next the admiral met Sir Knight Harris the subject came up, and he was told by Harris that "surface area is most important, and if Faraday says otherwise, then he knows nothing whatever about it!" Both, from their individual standpoints, were right.

150. The following rules may be mentioned as being those of best practice.

(1) "Use a good iron or copper conductor. If the latter, one of about six ounces weight to the foot and in the form of tape. If of iron, it should weigh 35 ounces to the foot, and be of tape form."—(McAdie.) "Iron is better than copper because while equally efficient as copper for rapidly alternating currents, it is more difficult to fuse."—(Lodge.)

(2) The top of the rod should in all cases be tipped with an indestructible, polished point, the earthed portion carried far enough below the surface to insure moist contact with the soil. It is good practice to securely fasten this by rivets to a copper sheet placed perpendicularly in preference to horizontally, in order to make contact with several layers or levels of soil, and thickly paint the riveted portion with asphaltum, to prevent electrolysis at that point.

(3) No joints not actually necessary should be permitted and these should be made firm with an abundance of solder, and well painted with asphaltum.

(4) "The rod should be detached from the building."—(Lodge.)

(5) "If the conductor at any part of the course goes near water or gas mains, it is best to connect it to them. Wherever one metal ramification approaches another it is best to

connect them metallically. The neighborhood of small bore fusible gas pipes, and indoor gas pipes in general, should be avoided."—(Lodge.)

(6) The greatest of care must be used in connecting lightning conductors to gas mains, by an abundance of solder or

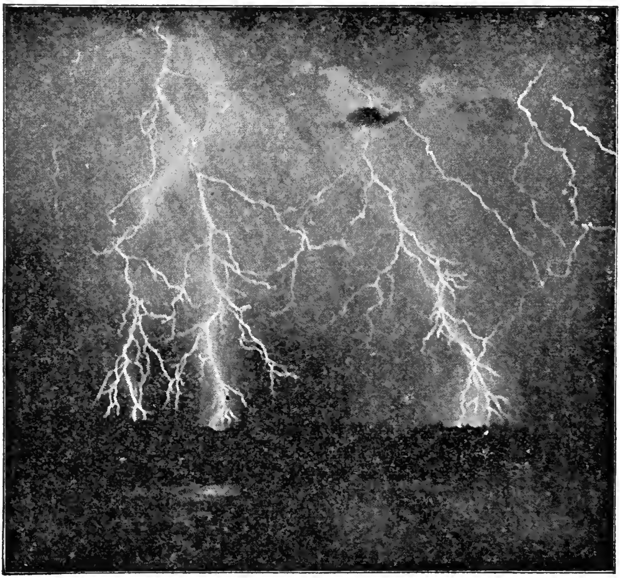


Fig. 17.

thorough brazing. A loose connection may fuse a hole in the gas pipe. Professor Trowbridge recently mentioned such an occurrence, which was fortunately discovered in time to prevent damage. The Hotel de Ville of Brussels, during a storm

while not struck, was damaged by fire, the result of an induced spark igniting the gas.

(7) Chains or linked conductors should never be used. The connections in these are very liable to rust.

(8) A multiplicity of rods, short but properly pointed, should be placed along the ridge pole of the structure: the more perfectly the whole is made to resemble Faraday's cage (52, ex. 3), the better.

(9) Never cross the inside of the building with a rod. Make firm metallic contacts everywhere, and ground the system in two or three places.

151. Two popular errors deserve notice. Pocket knives and the like do not attract lightning, and the attempt to insulate one's self with feather bedding is futile. In a rush or avalanche, such as shown in McAdie's photograph Fig. 16, a featherbed protection would hardly protect. On the other hand, during a storm, standing near animals is not wise; taking shelter in the doorway of barns, or seeking refuge under trees is far from safe, and a multiple flash, such as the one from nature by A. Binden, would be liable to ignore all such safeguards. Fig. 17.

152. The question "are thunderstorms more destructive to barns after harvest than before?" is thus answered by McAdie, in "Protection from Lightning."

(*a*) "Before harvest the stalks of the growing grains and grasses, with their many points and heads, act as conductors of electricity, and serve as discharging points, to some degree neutralizing the electrical stress in the air. After harvest the fields are more or less bare and the electric tension must be relieved through buildings and prominent features of the landscape.

(*b*) "The barn filled with crops is warmer than one that is empty, and is also more inflammable; if struck by lightning,

it is more likely to be destoyed by fire. Packed hay, for example, naturally makes a barn or stable warmer than its surroundings, and with the warmth there is more or less moisture. Uprising warm currents of air are probably formed, which, while not strong ordinarily, may be accentuated during thunderstorms, and play a significant part in determining the line of discharge. And, finally, barns, as a rule, are located on hills or hillsides, in positions to experience the maximum effect of currents due to heating or topography."

153. Despite the utmost precaution a human being may be struck by lightning. The blow may not be so severe but that the unfortunate may be restored to life if prompt, proper means are adopted to resuscitate the victim. According to Dr. A. H. Goelet: "Electric shock may produce death in one of two ways, viz.: By producing destructive tissue changes, when death is absolute, or by producing sudden arrest of the respiratory and heart muscles through excitement of the nerve centers, when death is only apparent; in other words, animation is merely suspended. The subject may be aroused from this syncope if efforts at resuscitation are not too long delayed."

154. Howard's method of producing artificial respiration has this advantage over other methods in that it can be successfully practiced by a single person, instead of two, and at the same time is equally efficacious. This, as given by McAdie, is as follows:

155. "Place the subject on his back, head down and bent backward, arms folded under the head, (under no conditions raise the head from the ground or floor). Place a hard roll of clothing beneath the body, with the shoulders declining slightly over it. Open the mouth, pull the tongue forward, and with a cloth wipe out saliva or mucus. Thoroughly loosen the clothing from the neck to the waist, but do not leave the subject's body exposed, for it is essential to keep the body warm; kneel astride the subject's hips, with your hands well

opened upon his chest, thumbs pointing toward each other and resting on the lower end of the breastbone; little fingers upon the margin of the ribs and the other fingers dipping into the spaces between the ribs. Place your elbows firmly against your hips, and using your knees as a pivot press upward and inward toward the heart and lungs, throwing your weight slowly forward for two or three seconds, until your face almost touches that of your patient, ending with a sharp push which helps to jerk back to your first position. At the same time relax the pressure of your hands so that the ribs, springing back to their original position, will cause the air to rush into the subject's lungs. Pause for two or three seconds, and then repeat these motions at the rate of about ten a minute, until your patient breathes naturally, or until satisfied that life is extinct. If there is no response to your efforts persisently and tirelessly maintained for a full hour, you may assume that life is gone.

156. "Hot flannels, water bottles, bricks, and warm clothing will aid in recovery. Warmth should be maintained, but nothing must prevent persistent effort as above described. Stimulants in small quantities may be administered after swallowing is possible, and sleep must be encouraged, as one of the best recuperatives. Get a physician as early as possible."

157. The treatment of persons shocked by electric light or power currents is identical with that for lightning stroke.

## CHAPTER VII.

### CHEMICAL BATTERIES.

158. We come now to a different method of developing electricity, through chemical action. Heretofore the electrical effects were of a spasmodic or fitful character, requiring the most perfect surroundings in the form of insulation, the dis-

charges for the most part explosive and sudden, as well as complete, or nearly so. There was no regular, continuous flow of current, the quality of pressure, of tension, being far superior to the quality of mass or quantity—it possessed volts in excess, amperes in deficiency; and was consequently not available for the many purposes which battery currents may be made to subserve.

159. *Experiment 1.* If a strip of zinc and a copper cent be placed touching the upper and lower surfaces of the tongue, as long as the two metals do not touch each other, little or no taste will be perceived ; but now, if the two metals be brought forward so that they touch, while still in contact with the surfaces of the tongue, a peculiar, metallic taste will be experienced, which is due to the electricity generated by the diminutive battery, made up of the two metals and an exciting fluid—the moisture of the mouth. The slight current evolved produces the effect on the nerves of the tongue which we know as taste.

*Ex. 2.* Two pieces of the metals just named are laid upon the skinned leg of a recently killed frog, one being in contact with the nerve governing the leg's action in life, and the other lying upon the lumbar muscle; when these are connected by a wire or other metal, the leg will be set in violent motion. This nerve has a different function to perform in life—it controls muscular movement.

*Ex. 3.* Hold a silver spoon in the space between the upper lip and the teeth, and with the other hand hold the smooth end of a plated table knife handle in the inner corner of the eye. Now close the eyes, and bring the blade of the knife down till it touches the spoon. A slight flash of light will be seen at the moment of contact. The effect will be more plainly marked if the strips of zinc and a strip of copper are each provided with a terminal. Now place these as in the former case, the zinc in the corner of the eye, or in contact with the inside

of the lower lid, and the copper held by the lip as before. Touch the terminal wires together, and the light will be seen as in the previous experiment.

160. In these three experiments we show that the electric current is capable of influencing three forms or kinds of nerves—those controlling taste; those controlling motion; and those controlling vision.

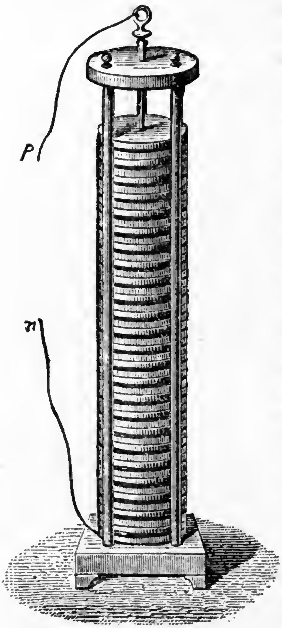



Fig. 18.
VOLTAIC PILE.

161. These effects may all be arrived at by the use of static charges, but from what we have seen in preceding chapters we know this form would be unsafe, because of its high voltage.

162. The form of electricity which we are now to consider is one which can be made to flow in a steady current, requires less insulation to prevent its escape, and may be handled with much less caution.

163. This second form of electricity is termed Galvanic or Voltaic, from the names of two of the earliest experimenters, Professor Galvani of Bologna, who in 1789 observed the motion produced in the legs of a dead frog by the means described in 159, and Professor Volta of Pavia, who constructed the first battery.

164. Previous to these developments only static electricity was known. Galvani explained the muscular action as the result of the bringing together of two electricities, the negative

of the muscle, and the positive of the nerve, which he assumed were something analogous to the parts of a leyden jar.

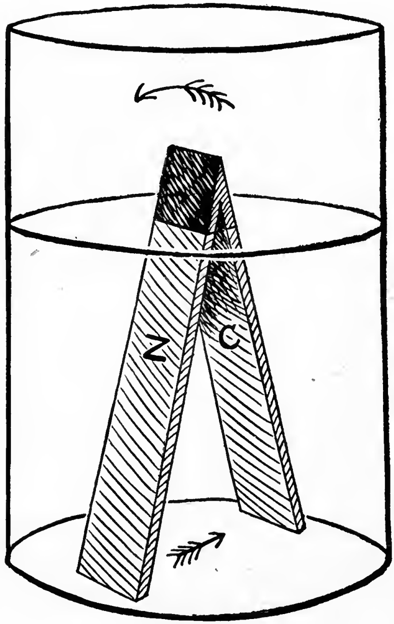



Fig. 19.

BATTERY CELL—CIRCUIT CLOSED.

165. Volta, not satisfied with Galvani's explanation, assumed that the result was accomplished by the joining of the dissimilar metals. He formed a column of a series of discs of copper, zinc and cloth in the order given, omitting the last

cloth. This gave a zinc terminal at one extremity and copper at the other. The cloths were dampened with acidulated water.

166. The developing of the current is due to chemical action, and a "pile" is far more active with some form of moisture which has the power of rapidly dissolving the metal attached. Acidulated or salt water, or common table vinegar, will develop far more energy than simple water, and discs of pasteboard or felt are preferable to cloth, because of their capacity for retaining the exciting fluid. Fig. 18.

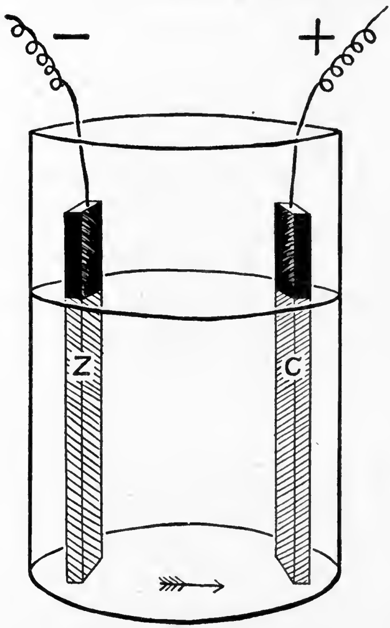


Fig. 20.
BATTERY CELL CIRCUIT OPEN.

167. From the pile to the battery was a natural and easy step. The simplest form of battery cell consists of a tumbler or jar, in which two slabs or strips of metal are placed upright without touching. One of these is of copper and the other is of zinc. Dilute sulphuric acid, one part acid to ten of water, is poured into the jar, and surrounds the two metals. There is a terminal wire soldered to each slab of metal. Now, so

long as the two terminal wires are kept apart little or no cur-

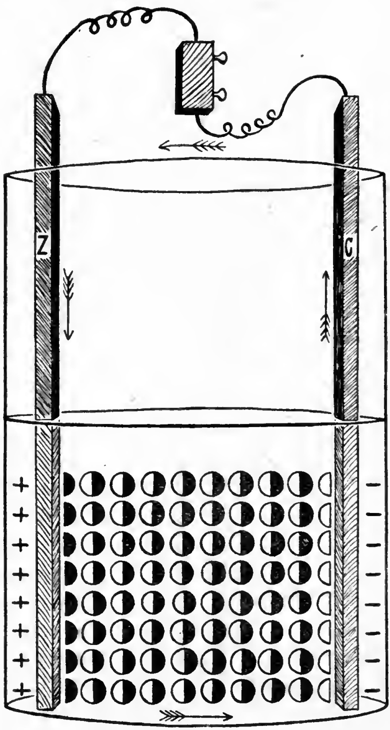



Fig. 21.

GROTHUSS' HYPOTHESIS—POLARIZATION OF ELECTROLYTES.

rent will be developed; but when these are brought together, a complete circuit is established. The zinc is at once attacked,

bubbles commence to form on the surface of the copper plate, and cover the plate.

168. Fig. 19 represents such a combination of metals and chemical fluid. In this the circuit, or path for the electricity developed, is readily traced, thus: Generated at the zinc plate, the stress or strain forces it to c, the copper plate, thence upward to the junction of c and z, and down to the place of beginning, in a constant flow, which will continue until the metal or the fluid is exhausted.

169. We now comprehend the marked difference in the characteristics of this and of the former electrical manifestations—differences entirely governed by the relative proportions of the two factors, potential and rate of current flow.

170. Now, if we separate the two metals at the top, where they are now in contact, the chemical action will cease almost entirely; completely if the various elements were chemically pure. We may attach a wire to each of these plates, outside the fluid, and we will find on bringing these terminals together that the flow of current will at once commence. Fig. 20.

171. The direction of the current flow is assumed to be from the metal which is most acted upon by the electrolyte, to the opposite metal or element, thence along the conductor outside the liquid, and back to the place of beginning. The metal most acted upon—zinc in the present instance—is the positive metal or plate, and the copper is the negative; but the current outside the liquid, is from the copper, which becomes the positive electrode or pole, and the zinc, inasmuch as it receives the current flowing back to the cell, is the negative pole or electrode.

172. We have in this form an example of a one fluid battery, a form which in a very short season of active work becomes weak, and eventually ceases to send out any current. The chemical action or energy, has changed the zinc into a solution of zinc sulphate, and the hydrogen contained in the

water collects on the negative element, the copper plate. This gaseous aggregation of bubbles introduces an element of resistance into the electrolyte and so prevents the current flow. This enfeebling of the battery is called polarization.

173. But there is still other pernicious effect of this accumulation of hydrogen gas on the copper electrode. The gas is highly active as an electrode and this combination develops a counter electromotive force—a tendency to send a current toward the zinc, in opposition to the current proper.

174. A theory of the action of a galvanic couple may be thus stated. Immediately on joining these two dissimilar plates in water there is set up an electric force at the surface of the zinc, because of its affinity for the oxygen of the water, which polarizes the whole combination. The molecules of water, consisting of hydrogen and oxygen, are polarized, and we may imagine these placed in series, their oxygen or negative portion toward the zinc, and their positive toward the copper. Now the first molecule at the zinc gives up its oxygen, and its hydrogen unites with the second atom of oxygen, the hydrogen set free combines with the next, and so on through all the molecules successively, until the hydrogen of the last molecule, having no oxygen with which to combine, is set free, attaching itself to the copper plate. Fig. 21. This explanation is by Grothüss.

175. In the case of an acidulated electrolyte we have a more active fluid, and it is perhaps the more probable hypothesis that the acid forms a zinc sulphate at once. In both cases the zinc is left clean, either by the acid dissolving the oxide, or the water dissolving the sulphate. In either case the result is identical—a series of discharges are sent through the circuit in such rapid succession as to form what we term a current.

176. The first effectual method of ridding the battery of this accumulation of gas is due to Daniell, a modification of whose invention is the common gravity battery. The original

cell consisted of an outer glass jar in which a copper cylinder nearly as high as the jar, was placed, and an unglazed earthen cell of less diameter stood within the copper. In this latter was placed the zinc plate in a solution of one part of sulphuric acid in twelve of rainwater. The outer cell contained a solution of sulphate of copper, and to keep this fully saturated a quantity of the crystals were kept in the jar.

177. The action of the battery up to the point of developing the bubbles of gas is the same as before described. This gas, carried through the porous unglazed cell, coming in contact with the copper sulphate, forms a new combination by decomposing this, carrying metallic copper to the copper plate, and releasing the sulphuric acid which was formerly part of the copper snlphate.

178. Other methods of disposing of the hydrogen bubbles have been proposed. Mechanical means, shaking the cell, blowing them away by a current of gas or air, or brushing them from the surface of the negative element, have been successful but not practical.

179. Much the same effect is arrived at in another form of cell, known as the Grove, from the inventor's name. Two receptacles, the outer of glass, the inner of porous earthenware, are filled, the outer one with a solution of ten or twelve parts by measure, with one of sulphuric acid, the inner with nitric acid. The metals are zinc and platinum. The hydrogen is reconverted as in the former example. This is the form of battery which was used on all the telegraph lines in America during the first few years of their existence. It was quite expensive, troublesome to keep in proper condition, and was gladly exchanged for the Daniell.

180. It was at once discovered that local action rapidly ate up the zincs, because of the impurities in the metal, and means were sought to counteract this evil. A remedy was found in amalgamating or coating the zincs with mercury. The impuri-

ties which thus affected the battery detrimentally are iron, lead, carbon, copper, and in less quantities some other metals.

181. Some of these elements are positive and others are negative to the zinc, so that there were cross currents in every direction in the zinc until the application of a mercurial coating put an end to the annoyance.

182. The greater the difference between the two electrodes, from the standpoint of their resistance to the action of acids, the greater the electrical force which may be developed. Oxidable, chemically speaking, is almost a synonym for electro-positive. In the following list the first named is electro-positive to the next, and so on successively through the list, the last being electro-negative to any of the rest. Potassium, sodium, magnesium, zinc, iron, lead, copper, silver, platinum, hydrogen, carbon, chlorine, sulphur and oxygen.

183. From this we judge that a zinc and silver battery, or one of zinc and carbon or platinum would be more effective than one of zinc and copper. In practice this is found to be true, and in proportion as the chemical action of the electrolyte is intensified the electrical result is heightened also.

# CHAPTER VIII.

## CHEMICAL BATTERIES (CONTINUED).

184. The improved form of Daniell battery, known as the Callaud or gravity, which displaced the form described, has no porous cell, or cup, it having developed by experiment that the difference of specific gravity between a copper and a zinc solution would completely separate these, if permitted to remain quiet, and the separating material was no longer necessary. The internal resistance of the cell was also materially lowered, which was another marked advantage. This form of cell is one of the most reliable for constant use, as it only requires material in the form of zinc and copper sulphate, to furnish a steady current. It is necessary to keep it in use, otherwise the copper solution will rise to the zinc, as there is no action of consequence when the circuit is open. On the other hand constant use will develop zinc solution in excess, and crowd down the copper solution. When this occurs part of the zinc solution should be removed, preferably with a battery syringe, and the jar again filled with water.

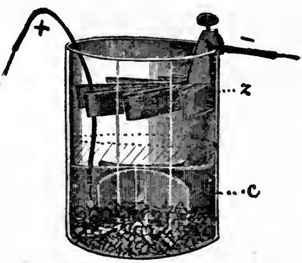


Fig. 22.

TWO-FLUID BATTERY.

185. Figure 22 shows a Callaud cell, in the bottom of which lies a quantity of copper sulphate (blue vitriol) crystals. C is the copper electrode, made up of strips of thin sheet copper

riveted together so that it will stand in the position shown. Riveted to this is a copper wire, which, save at the copper electrode, is covered with waterproof insulation, usually rubber or gutta percha. This wire terminates at the + pole of the battery. Z is the zinc, to which is attached the — terminal. The dotted line shows the proper line of demarkation between the two fluids.

186. The constancy of this form of cell is attributable to the fact that every time a molecule of sulphuric acid is decomposed a molecule of sulphuric acid is released by the deposition of the metallic copper held in the copper sulphate solution. The zinc is constantly lessened by being made into zinc sulphate, and the copper plate aggregates by deposition on the yielding up of its sulphuric acid by the copper crystals.

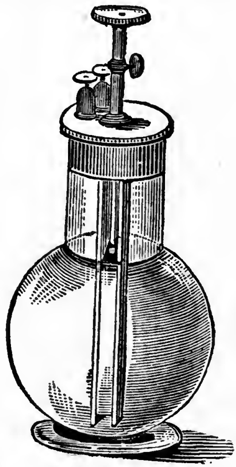


Fig. 23.

GRENET CELL.

187. We have now seen two batteries typical of the one and two fluid forms. There are many varieties of these, and from the wide range from the positive element, potassium, to the negative, oxygen, combinations of elements far apart should theoretically be more active than of those nearer together in the scale. Thus zinc and platinum or zinc and carbon would naturally be more active in combination than zinc and iron or zinc and copper. This theory is borne out in practice; and again in proportion as the chemical action is intensified the electrical result is increased.

188. Other acids besides sulphuric are used, either simple or combined in various metallic salts. Thus the Grenet, or bi-

chromate battery, has for the electrolyte a solution of bichromate of potash and dilute sulphuric acid, with electrodes of zinc and carbon; for a short period of time where a strong current is required this is an excellent form, but it rapidly polarizes, and requires to be rested by opening the circuit. Its electromotive force is about 1.9 volts, while Daniell's is only 1.072.

189. The Smee battery has an electrolyte of dilute sulphuric acid and electrodes of zinc and silver. Its e. m. f. is only about 0.6 of a volt. When not in use the zinc is raised out of the solution.

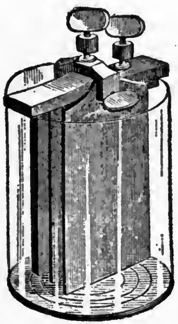


**Fig. 24.**
SMEE CELL.

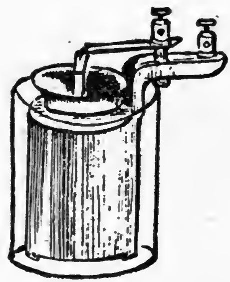


**Fig. 25.**
GROVE CELL.

190. An example of two fluid cells is Grove's, in which a porous cup filled with nitric acid is encircled by a cast zinc, this combination being held in a large glass tumbler containing acid and water. Attached to a horizontal arm of the zinc by soldering, a thin slip of platinum depends, which is immersed in the nitric acid, if there is a combination of cells. Otherwise the platinum is soldered direct to the circuit wire.

The depolarizing of the platinum plate is assisted by the nitric acid, which furnishes the requisite oxygen to combine with the hydrogen and form water. This action rapidly dilutes the nitric acid, and a renewal is necessary after a short season of constant work, in consequence. In the early days of Morse telegraphy these batteries were taken down every night, the zincs brushed and amalgamated, and one-half the nitric acid thrown away, while one-half new replaced the

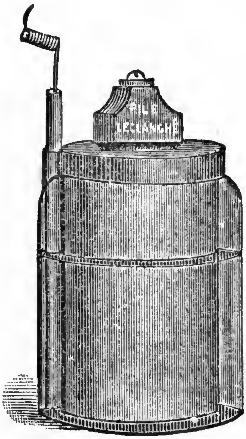



Fig. 26.
ORIGINAL LECLANCHÉ CELL.

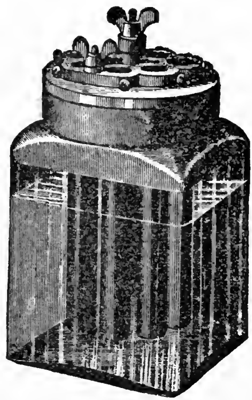


Fig. 27.
IMPROVED LECLANCHÉ CELL.

waste, daily. The e. m. f. of a Grove cell is 1.03 volts. The Bunsen cell differs from the Grove only in the substitution of carbon for platinum. Its e. m. f. is the same as Grove's.

191. A peculiar form of open circuit battery which seems either a one or two fluid battery is the Leclanché, when it is viewed from different standpoints. The zinc is surrounded by a solution of sal ammoniac contained in a glass jar. The nega-

tive element, in the original form, consisted of a plate of carbon, closely packed in a porous cell, in a mixture of black oxide of manganese and broken gas retort carbon. The carbon plate rose above the cell, which was sealed with either paraffine or similar material, only two small holes being left for gas escape. The carbon surface was thus made quite large. The part played by the black oxide of manganese is similar to that of the nitric acid in the Grove cell.

192. A much improved form of this battery cell dispenses with the porous cell, the negative element being made up under severe pressure into either plates or cylinders. A typical form is shown. The Leclanché cell rapidly polarizes, but recovers readily. Its e.m.f. is nearly 1.5 volts. The solution should not be so filled as to leave a quantity of the salt in the bottom of the cell. A saturated solution is best. When the battery gives out it may be renewed by cleaning and filling with a new solution. The carbons will be improved by soaking a few hours in a bath of tepid water.

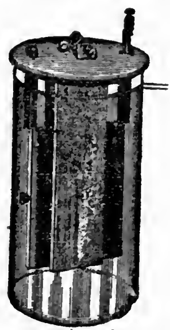


Fig. 28.
EDISON-LALANDE CELL.

193. A form of active and quite constant battery, something on the order of the bichromate of potash batteries, is made up of plates of oxide of copper for the one electrode, and zinc plates for the other. The solution is of caustic potash, which is furnished in the form of rods. In order to prevent the creeping over of the salts, the jar which contains the fluid is not filled to within a couple of inches of the top, and a layer of heavy oil is poured on the solution to the depth of one-quarter of an inch. There is virtually no action when on open circuit (less than one-half of one per cent), and the cell requires no attention, as evaporation is completely prevented by the oil; and to renew it only requires the addition of the sticks of

potash. The e. m. f. of this cell is .80 volt, and its internal resistance being only .025 of an ohm, the quantity of current generated makes this form of cell available for small motors, for running sewing machines, phonographs, etc.

194. The chemistry of this cell is interesting. As has been stated, when the circuit is open there is no chemical action of consequence, but immediately on closing the circuit the oxygen, as in other batteries, at once attacks the zinc, forming an oxide of zinc, which now combines with the potash solution, forming a double salt of zinc and potash, which immediately dissolves and the hydrogen set free goes to the copper plate and is disposed of by combining with the oxygen of the copper salt and freeing the metallic copper.

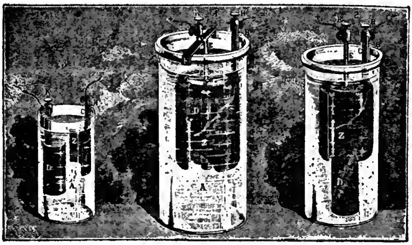


Fig. 29.

IMPROVED FORM OF DE LALANDE CELL.

195. Like most electric batteries this one has recently been undergoing some important changes by the inventor, De Lalande. Fig. 29 shows this improved form. Three sizes are given, in different sections as well as dimensions. The new arrangement prevents the deposit of copper on the zincs, a fault also with the original Daniell's cell. The oxide of copper is now placed in cylindrical boxes of perforated sheet iron, and surrounded by a porous diaphragm of feeble resistance. The potash is placed in tin boxes which are suspended over the jar. and leak a thick solution of potash into the cell. The zinc Z is suspended from the edge of the vessel A by a hook B, and is provided with a strip C, carrying a terminal, H. In the center

there is an oxide of copper cylinder held away from the zinc by four porcelain insulators I. The zinc is connected with a strip E, which rests tnrough an elbow on a crosspiece F, and carries a terminal K. In general the three models are the same in principle, differing slightly in construction. The smaller element is 8x4 inches, capacity 75 ampere hours, e. m. f. .80 of a volt; the medium size 13x6, capacity 300 ampere hours, and will give out 3 to 4 amperes in normal work; the larger size is 14x7, capacity 600 ampere hours, and can be made to yield a discharge of 15 to 20 amperes. The e. m. f. of the two latter is the same as that of the first.

## CHAPTER IX.

### CHEMICAL BATTERIES (CONTINUED).

196. Batteries then, as far as we have studied them, may be divided into two grand divisions, those with but one and those with two solutions. The former are directly traceable to the original pile, although the exciting fluid may be either an alkaline or an acid solution, and the electrodes may vary materially. Again, these last need not both be metallic, carbon often forming the negative element, as we have seen in some of the forms shown in the last chapter.

197. Single fluid batteries present the serious objection, which has been explained (172), of polarization. Some of these rapidly recover, if left on open circuit, and for that reason this class of battery is of excellent service where the demands upon it are of an intermittent or occasional character, the intervals between service allowing it to recuperate. For call bells, telephone service, burglar alarms, gas lighting and the like, it is reliable and ever ready. It is also greatly in the favor of these batteries that there is little or no wasting action when the battery is out of use—on open circuit.

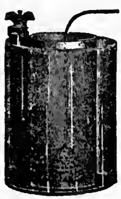


Fig. 30.

FULLER CELL.

198. One of the most available of these, for purposes analogous to telephone and call-bell work, is a modification of the Grenet, or bi-chromate cell. The advantages of this cell — the Fuller—Fig. 30, are the high voltage—nearly two volts — the automatic amalgamation of the zinc, and the little attention required to keep it in order.

199. The elements in the Fuller cell are zinc and carbon. The electrolyte is a mixture of one pound of bi-chromate of potash in 10 pints of water, in which 2½ pounds of sulphuric

acid has been mixed. Care must be taken to pour but little acid at a time, and this should be thoroughly stirred with a glass rod before adding more acid. In the mingling of these two liquids a large amount of heat is given off. This liquid is called electropoion liquid.

200. The Fuller cell is a zinc-carbon couple, and consists of a glass jar in which the carbon plate is placed, and a porous cell in which the zinc is placed. The zinc. of the form shown, is surrounded with pure water, and rests on the bottom in a layer of mercury. The outer cell is filled with electropoion solution diluted with about forty per cent of water. The water surrounding the zinc soon becomes acidulated; the mercury keeps the zinc amalgamated, and the evaporation of the cell only requires the addition of water.

201. The two fluid batteries are equally numerous, and are all, or nearly all, descendants in a direct line of the Daniell or the Grove. The two fluids are separated either by their different gravities, or by a diaphragm. In the various modifications of the Daniell the former is frequent, while in those which are more nearly allied to the Grove, a diaphragm or porous partition holds them asunder except through infiltration.

202. While nearly all the metals mentioned (182) are used as elements, the solutions used for electrolytes are hardly less varied, and the e. m. f. of the various forms occupies a wide range. The e. m. f. of these combinations, in single fluid batteries, ranges from .191 in a cadmium-iron cell with dilute sulphuric acid as an electrolyte, to 1.537 in hydrochloric acid with amalgamated zinc and platinum elements. In two fluid batteries the range is from less than half a volt where copper and iron are the elements, and sulphate of copper and sulphuric acid form the fluids, to nearly two volts where platinum and zinc with strong nitric and dilute sulphuric acids are used.

203. In addition to the one and two liquid cells there are cells which are erroneously called dry cells or dry batteries, but

which contain sufficient moisture to provoke chemical action and develop current. These are formed of two electrodes and a damp chemical paste containing no superabundant moisture, and closely sealed. The containing case is often one of the electrodes—commonly of sheet zinc. This form of cell, while not of a lasting character, is convenient and can be placed where the ordinary liquid cells would be objectionable, as the small amount of moisture contained cannot escape. The principle of action is the same as has been explained hereto-


Fig. 31.


Fig. 32.

MODELS OF DRY BATTERIES.

fore. Figs. 31 and 32 show so-called dry cells in different models.

204. A third form of cell and one of no inconsiderable value is the storage or accumulator, or secondary cell.

205. This form of cell was original with Planté, who announced in 1859 that a material current could be drawn from a combination of two electrodes of the same metal, with a single

electrolytic fluid through which a current from a primary source has been sent.

206. The earlier batteries of M. Planté were constructed as shown in Figs 33 and 34. Two sheets of lead kept apart by strips of rubber, are closely rolled together and placed in a glass or hard rubber jar. A solution of one part of sulphuric acid to ten of water is poured into the jar and the two terminals are then connected to the poles of a battery. The current is thus short circuited through the secondary cell.

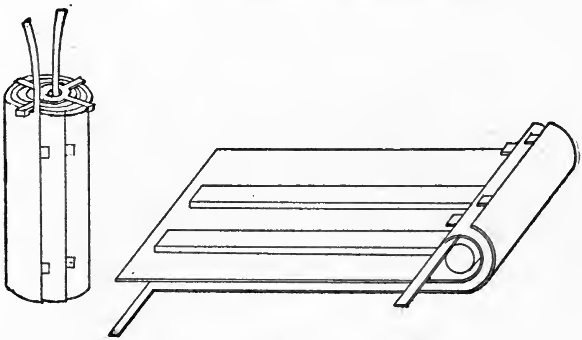


Fig. 33.

PLANTE CELL DISSECTED.

207. The electrolytic action of the current affects the metallic lead of the two plates differently, for the current enters at one of these and returns to the primary battery through the other. One of the plates becomes coated with a salt of lead (peroxide), having a brownish color, while the other plate changes to a grayish hue, being covered with finely divided, spongy lead.

208. The cell having been fully charged and the primary battery removed, on connecting the two terminals of the sec-

oudary through proper instruments, current is found to flow in the opposite direction to that of the charging current—from the spongy lead, through the fluid to the brownish plate, and back through the outside circuit.

209. In the electrolytic action (207) the compound molecules of the fluid are separated—decomposed—into two groups

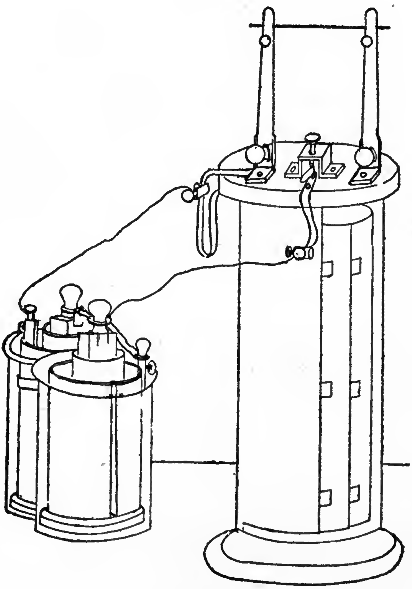


Fig. 34.

PLANTE CELL BEING CHARGED BY BUNSEN BATTERIES.

of atoms or radicals, one of which is electro-positive, the other electro-negative. These divisions of the molecules are called *ions*, the former being *kathions*. the latter *anions*.

210. To aid the memory in retaining these facts the following has been suggested:

The copper pole the anode is,
  And positive as well,
While zinc the kathode is we know,
  For scientists so tell,
And anions round the anode cling,
  As if it were their goal,
While kathions are repelled from thence
  And seek the other pole.

211. In the original Planté battery the plates, in order to render them more effective, were required to be "formed"—a term original with the inventor—which was accomplished by repeatedly charging and reversing the current through the electrolyte, the secondary battery being discharged between each two changes of current direction.

212. The limited capacity of the Planté battery, as well as the difficulty of "forming" which required much labor, early induced investigators to seek some method of overcoming these objections, and M. C. Faure, a member of the French academy, at its meeting of April 18, 1880, announced an improvement which consisted in making the plates with a roughened surface into the inequalities of which a paste of an oxide of lead could be placed, thus doing in a few minutes what Planté required weeks to accomplish. Where the plates were of considerable length, they were rolled similarly to those of Planté.

213. Various improvements rapidly followed, until to-day the storage battery has generally assumed the forms shown in Figs. 35, 36, and 37, and what was looked upon in its infancy by many prominent electricians as a pretty scientific toy, like the telephone, has to-day assumed a very important place in electrical commerce. A very large plant of this form of battery is in daily use by the Chicago Edison Company, comprising 166 cells of 87 plates each, in tanks 21½ inches wide, 79¾ inches long and 43⅞ inches high, weighing over three tons. Another form of storage battery consists of sheets of lead

formed up like dinner platters, piled in each other like crockery plates. Each plate, save the lower one, is coated on its under surface with litharge, the upper dished surface containing red lead, covered first with asbestos and then with pulverized charcoal, and over this with a thin sheet of muslin. The two surfaces of each sheet constitute the negative and positive poles of one cell. Piling them like crockery ware arranges them in series, while the size of the plates governs the current flow. This is the invention of Professor Edgerton, of Pennsylvania. The plates are partially filled with dilute sulphuric acid, and the battery is charged, as are all storage batteries since the dynamo was brought forward, by current from that electric source.

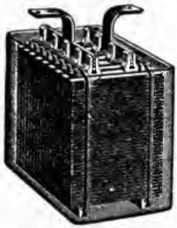


**Fig. 35.**
IMPROVED STORAGE CELL.

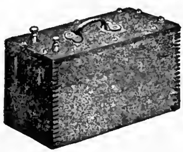


**Fig. 36.**
PORTABLE STORAGE CELL.

**Fig. 37.**
BICYCLE CELL.

214. The earth has been used to a very limited extent as an exciting electrolyte for a battery. A sheet of copper buried in the earth becomes one element, while a zinc sheet forms the other, both being planted sufficiently deep to insure constant moisture. The wires leading down through the earth to these should be covered with rubber or gutta percha to prevent short circuits. The terminals above ground will, when brought together on a proper instrument, show developed electricity.

215. Alexander Bain, of Edinborough, the inventor of chemical telegraph recorders, constructed a clock, which was moved by electricity obtained through a battery described in the last paragraph, and was in use for some years in an office in Broadway, New York. Others also have done the same. Steinhill used an earth battery with moderate success for telegraphic purposes.

216. An electric clock may be operated by a ground battery, arranged as shown in Fig. 38, where P represents the pendulum, M, $M^1$ the electro-magnets actuated by the battery B. At the lower extremity of the pendulum a soft iron armature A, as the pendulum swings to and fro, plays loosely in the two electro-magnets. Two spring contacts, C and $C^1$, independent of the pendulum, by means of the wires W and $W^1$ alternately make contact, closing the battery through the electro-magnets, attracting the soft iron armature A. As the pendulum is moved in either direction the escapement E actuates the movement of the clock. The pendulum acts as a key in the circuit, and makes and breaks contact automatically at C and $C^1$. In the position shown the circuit is closed through $M^1$ which will move the pendulum to the right. This movement will break the circuit at $C^1$ and close it through C, W, and M, and reverse the motion of the pendulum, and then re-reverse its motion. Sufficient spring is given C and $C^1$ to allow the full swing before reversing.

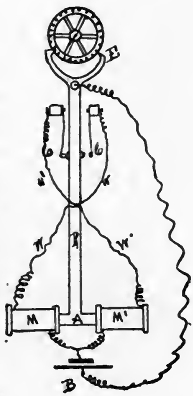


Fig. 38.
ELECTRIC CLOCK.

217. It is evident, from what has gone before, that an earth battery, which by means of exciting fluids, acid or alkaline, might be made more active, would still lack e. m. f., because

we would have but a single cell. To increase the e. m. f. of a battery we increase the number of cells; while to increase the current flow we increase the size of the elements.

218. Heretofore we have considered but a single cell. We are now to consider combinations of two or more, and study the result of such aggregations.

219. Suppose we have three cells which we will connect together as shown in Fig. 39. The positive pole of one cell is attached to the negative of the next, the second positive to the third negative. Now, when we attach a wire terminal to the negative pole of the first, and another to the positive of the last, these wires will be the terminals of the combination, as before they were the terminals of a single cell.

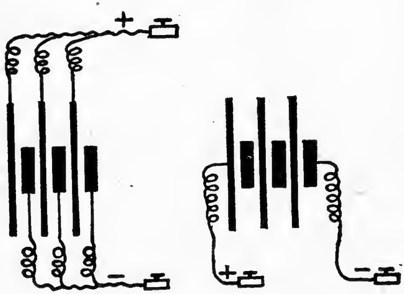



Fig. 40. Parallel Coupled for Current.

Fig. 39. Series Coupled for E. M. F.

BATTERIES GRAPHICALLY REPRESENTED.

220. Each of these cells has an equal e. m. f. which we will assume to be 6 units, but has an internal resistance of 2 units, against which the current is required to force its way (36 to 44). The amount of current then will be $3 \times 6$ divided by $3 \times 2$, which will be no more current than we got from a single cell,

for 18 divided by 6 is the same as 6 divided by 2. With this combination then we have increased the e. m. f., but have not changed the amount of current.

221. Suppose we had 30 cells connected similarly—that is, in series, 30×6 units=180. This divided by 30×2 will show the same result in the amount of current flow, 3 units.

222. Now, let us change the combination by connecting our three positive elements together for one terminal, and the three negative elements for the other terminal. We now have but one cell in the place of three, but we have reduced the internal resistance of the battery until it is one-third what it was, and we have also reduced the e. m. f. from 18 units to 6. The current flow will now be 9 units, or six divided by ⅔. Fig. 40.

223. In all cases then we may increase the current flow by increasing the area of the elements—thereby decreasing the resistance of the battery—and we can increase the e. m. f. by increasing the number of elements.

224. If there are other resistances beside that confined to the battery itself—that is, if we have additional wires, telegraph instruments and the like, then these resistances must be taken into the calculation, also, in ascertaining the current flow.

225. Certain living creatures possess within themselves powerful apparatus for the development of electrical phenomena. The most striking examples of this faculty are found in the electrical fishes known as the *raia torpedo* and the *gymnotus electricus*

226. The first of these is one of a large family, some species of which occasionally reach 100 pounds in weight. Its electrical battery consists of a number of hexagonal prisms, (varying in number with the age of the individual) on either side of the fish, between the head and the gill or pectoral fins, arranged much like the cells of honeycomb. Each battery has four nerves, branches of the fifth and eighth cerebral nerves, so that the nervous center of the apparatus is the *medulla oblongata.*

This fish and its kindred species is found in the Mediterranean and the Bay of Biscay.

227. The second fish, the *gymnotus*, is found in Surinam. It inhabits all the streams which flow into the Orinoco. It sometimes measures six feet in length. The digestive apparatus, the viscera and accompanying organs occupy but about two inches of the body next the head, the rest of the body comprising four batteries—two on either side, one above the other, the upper being the larger. These are not unlike a horizontal voltaic pile (165). The superior battery has from 30 to 60 cells, while the inferior numbers from 8 to 14. Over 200 pairs of nerves lead to these cells from the motor roots of the spinal nerves. Faraday estimated the electrical force of each medium discharge of a specimen 40 inches in length, with which he experimented, as equal to that of a fully charged Leyden battery of 15 jars, having a surface of 3,500 square inches. The most severe shocks are given when contact is made at the head and tail, while intermediate or shorter contacts provoke proportionately less results.

228. The thunder fish or *raash* of the Nile is one of another family of electrical fishes, a second of these having recently been found in the waters of the old Calabar river, in the Gulf of Guinea, Africa.

229. Nobili found that when a delicate galvanometer* was placed in circuit with the nerve and muscles of a frog's leg, a marked deviation of the needle occurred, and that this effect was increased when several legs were connected in series. The current was shown to pass from the toes upward, and the experiment proved conclusively that electricity is developed in connection with muscle and nerve.

230. Matteucci and Dubois Reymond have shown conclusively that in a living animal there is an electrical current per-

*Galvanometer—an instrument for detecting and measuring currents of electricity, whieh will be explained in a coming chapter.

petually coursing between the internal and external portions of a muscle, probably due to the chemical changes constantly occurring in the animal tissues.

231 *Experiment 1.* Five or six frogs are killed by severing the spinal column directly back of the head. The lower limbs are then removed, and the skin stripped off. Cut the thighs off at the knee joint, and cut the thighs across transversely. The lower halves are now laid upon a varnished board, arranged so that the knee joint of one limb shall touch the transverse section of the next. We shall now have a battery arranged in series, consisting of ten or twelve cells. The terminal pieces of the battery are made to dip into small cavities in the board containing distilled water—this being incapable of producing any chemical effect and thus leading us into error. Now, with a pair of wires leading to a sensitive galvanometer, having platinum terminals, complete the circuit by dipping these into the water terminals of the battery, and a deflection of the needle will show the existence of a current from the center to the surface of the severed muscles.

232. Other experimenters have shown that the mucous secretions of the alimentary canal and the blood are in opposite electrical conditions, and the hepatic, the renal and the mammary secretions are in an opposite electrical state from the venous blood flowing from the several parts.

## CHAPTER X.

### OTHER METHODS OF DEVELOPING ELECTRICITY.

233. There are, in addition to the preceding, other means of developing electric phenomena, which, while comparatively of small value in practical use, are still of interest to the student and experimenter.

234. Two dissimilar metals, when brought into metallic contact, will develop a slight electrical effect, which requires delicate instruments to detect. This fact formed the basis of the contact theory of the voltaic cell, which assumed that the mere contact of the two elements of the cell, through the medium of the electrolyte, set up the potential difference of the cell.

235. This result of contact is quite generally believed to be owing to the fact that the two elements are surrounded by air or ether, which acts as an electrolyte. The difference of potential is quite small, as the following comparative table by Ayrton and Perry will show, the first named element being positive to the one following. The difference of potential is given in thousands of a volt:

| | | | |
|---|---|---|---|
| Zinc, Lead | .210 | Iron, Copper | .146 |
| Lead, Tin | .069 | Copper, Platinum | .238 |
| Tin, Iron | .313 | Platinum, Carbon | .113 |

236. The difference of potential between zinc and carbon will be found by adding the various differences as a total sum —1.089.

237. These differences may be made to rise quite materially by submitting the elements to increasing temperatures, and

the potential difference may also be reversed in some instances by the same means.

238. Thus at zero Centigrade, platinum is + to lead, while in raising the temperature to 150° C there is a gradual lessening of this difference, until a point is reached when there is no electrical phenomena exhibited. If now the temperature is still further exalted, a reverse polarity increases. At zero Centigrade the zinc is + to the platinum 3 microvolts (millionths of a volt); at 150° C there is no potential difference, while at 600° C the p. d. is 9 microvolts.

239. These facts are utilized in the formation of a form of cell or battery known as the Thermopile. A simple model of this is given in Fig. 41, which represents a bar of bismuth B, and a bar of antimony A, joined at J by soldering. To the outer ends of these elements are soldered wire terminals, W N. If now we heat the junction J a current will flow from the bismuth to the antimony, and through the united terminals back again, when these last are connected.

240. We may join a number of these combinations, as we join batteries, for e. m. f., as shown in Fig. 42, where z, z, z., etc., represents bars of an alloy of zinc and antimony, and I, I, I, etc., bars of iron, the two elements arranged in series. Terminals W, W′, serve for connections. Within the space inclosed by this combination of elements, arranged in circular form (Fig. 43), heat is applied at H, while the outer parts are kept cool. By arranging several of these last combinations one above the other, and uniting the W′ terminal of one set to the W terminal of the next, we can have a combination which will give the aggregate e. m. f. of the whole series.

241. This arrangement is credited to Clamond, and electric power has been developed in this manner to produce an electric arc equal to 40 carcel lamps; but the use of this form of battery has not so far been found sufficiently practical for general use.

242. Thomson has shown that a difference of potential may be set up in a homogeneous substance unequally heated, and Peltier has shown that a current of electricity through a combination, such as shown in Figs. 42 and 43, will develop a

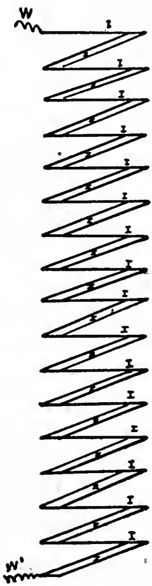



Fig. 42.
THERMOPILE
OF SEVERAL COUPLES.

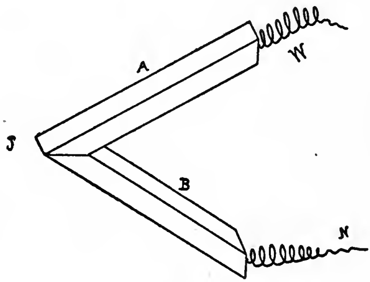



Fig. 41.
SIMPLE THERMOPILE.

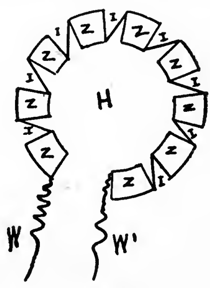



Fig. 43.
CLAMOND'S THERMOPILE.

change of temperature, higher or lower, according to the direction of that current. The amount of heat developed or absorbed will be proportioned to the strength of the current.

The Peltier effect is the reverse of the effect shown to be the result of heat application.

243. Still another effect, the Joule effect, is present in a thermo-electric combination. As has been mentioned previously, the passage of any electric current through a conductor is obstructed by the resistance of that conductor (42). In all cases this obstruction results in the development of heat. This is known as the Joule effect, and it will be readily understood that these various effects, as they are called, render the action of a thermo-electric couple or Thermopile extremely complicated and difficult of explanation.

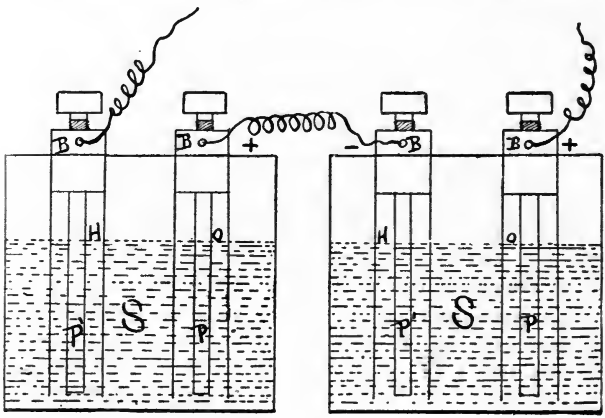



**Fig. 44.**

GAS BATTERY.

244. Another form of battery is shown in Fig. 44, in which the elements are gases in place of solids.

245. A gas battery comprises an outside receptacle or jar, partially filled with dilute sulphuric acid, S. Standing in this

fluid are two cylinders of glass, closed at the upper end, but open at the lower, below the level of the fluid, which latter partially covers the platinum plates, P. P′. The space above the fluid line in each of these cylinders is filled by electric decomposition of the electrolyte, the one marked H with hydrogen, the one marked O with oxygen. The platinum plates are connected to the binding posts B B, which serve as terminals, and to which the conductors are connected.

246. To charge a gas battery an electric current is sent through it from an independent source, until the electrolytic decomposition of the liquid has released the amounts of gases required. When the charging source has been withdrawn, connecting the two terminals B B through a galvanometer will show the presence of a current flowing in the opposite direction from the charging current. The gas battery in this respect is closely allied to the storage or secondary form of batteries; but it may be made operative by feeding gas into the cylinders O H without previous charging. The gas battery has no commercial value up to the present time.

247. Sunlight properly applied may be made to develop electrical effects. If a mass of the metal selenium be fused between two metal conductors, preferably of platinized silver or of platinum, the two metals can be made to develop electrical phenomena.

248. One form of cell is composed of two platinized plates between which selenium is cast, the plates being held firmly in place until the metal has cooled. The cell is afterward tempered, and the selenium is changed from the condition of cast or amorphous metal to the sensitive form by repeated heating and gradual cooling.

249. On exposing one of the electrodes of such a cell to bright light, the development of electric phenomena is instantaneous, and these disappear with the withdrawal of the light in an equally sudden manner.

250. An application of the selenium cell has been made to automatically turn on an electric lamp at the approach of darkness, and reversing the process at the coming of day, to extinguish the light. This is effected through the medium of an electro-magnet and a switch which it controls.

251. Another utilization of the sensitiveness of selenium has been shown in an alarm apparatus, whereby a light in the hands of a burglar, or a fire in the neighborhood automatically rings an alarm bell, and calls the attention of the inmates of the building so protected.

## CHAPTER XI.

### TERRESTRIAL MAGNETISM.

252. One form of iron ore, known in mineralogy as the protoxide, or octahedral ore, possesses the peculiar property of attracting to itself particles of iron, and holding these when in contact with them, with more or less force; and occasionally a fragment is found which possesses polarity—an inclination under p oper circumstances, to assume a nearly north and south position.

253. From this peculiar faculty of attracting iron has arisen several names by which this mineral is known. From the Saxon *læden*, to lead, comes lodestone (leading stone), love stone it was sometimes called by our forefathers, and the same signification is found in the French *l'aimant*. In English it is commonly known as magnet, a name derived from its Greek origin—magnesia, in Lydia—but Maine, Arkansas, Pennsylvania, New Jersey, Michigan and other states, have contributed large quantities of magnetic iron ore to science and to commerce.

254. The earth on which we reside is one huge magnet, having its north and south poles nearly in the line of its axis of rotation.

255. The faculty of induction, which we have learned is an attribute of electricity, is also possessed by a magnet. This inductive influence of the earth's magnetism is exerted everywhere, and results in making magnets of greater or less strength of all steel or hard iron which is permitted to remain long in one position.

*Experiment 1.* Procure a small pocket compass, and hold this so that the needle will move freely, against an iron stove-

pipe. Raise and lower it past the joints in the pipe, and as a rule the action of the needle will show that there is a change of polarity at each joint, the ends of the needle being alternately attracted in passing.

*Ex. 2.* With the same compass explore the polarity of any permanent piece of iron, such as a balcony, an iron safe, a gas or water pipe which lies in a north and south position, and it will generally be found that the north and south extremities between joints will show different polarities.

*Ex. 3.* Explore the polarity of a street car rail lying in a north and south street. Its polarity will be found to be lengthwise of the rail. Now try a rail lying in an east and west position, and it will generally show a polarity at right angles to the length of the rail—the north side will show one polarity, while the south will show the other.

*Ex. 4.* Take a fine cambric needle from a package which has been lying in a north and south position, and drop it carefully on a glass of water. In the majority of cases, if properly handled, it will float, and generally show polarity by settling in a north and south position.

*Ex. 5.* If now, while this needle is lying on the surface of the water we approach it carefully with the compass, one pole will be attracted, and the other pole will be repelled. That is, the two ends of the compass needle will repel the like ends of the floating needle, but will attract the dissimilar ends. This experiment may be made still easier by floating the needle with a tiny bit of cork through which it has been thrust.

256. In magnetism then we learn that similar polarities repel, while opposite poles attract each other; and that the inductive action of magnetism may take place at a distance, without metallic contact. But it is also true that a stronger influence results from actual contact: and that the strength of attraction which any magnet may have for any piece of iron is governed solely by the distance between them; an attraction

which follows the general law governing all diverging forces. We may illustrate this readily by means of light rays.

*Experiment 1.* Procure a piece of stiff cardboard (the cover of a shoe or envelope box), in the center of which cut a smooth, square opening as shown in Fig. 45. Cover a table with newspaper, on the margin of which mark off inches. You will want a dark screen, which can be made by covering a large book with dark paper or cloth, and standing it upright,

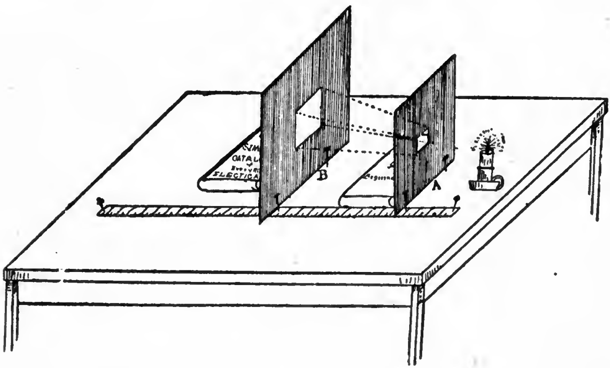



**Fig 45.**

THE LAW OF INVERSE SQUARES.

on the table. So arrange the light and the board A as to bring them level, and screen B at the same height from the table. Now, place the screen B at such a distance that the light spot is one inch square, and note the distance between A and B. Double the distance by moving B, and the spot will be four times as large. The experiment will be more interesting if the screen is laid off in inches. If we move the screen back to three times the original distance, the light image will measure

nine square inches instead of four—nine being the square of three.

257. The light from the candle diverges or radiates in all directions, and inasmuch as it covers more surface as the distance increases, the light is less intense in proportion.

258. Magnetic attraction and repulsion follow the same invariable law—the law of inverse squares. All radiating forces decrease as the square of the distance.

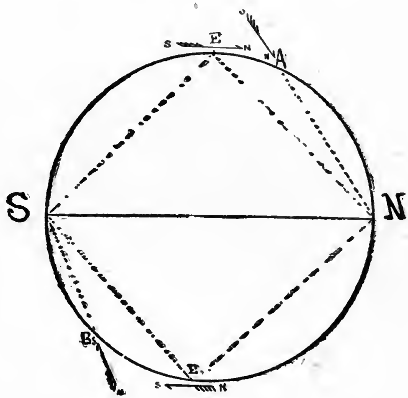



Fig. 46.

DIP OF THE MAGNETIC NEEDLE.

259. Magnetic attraction set up by the earth is the directive force actuating the mariner's compass needle. The needle, which is an artificial magnet, is attracted by the magnetism resident in the earth, and indicates thus a generally north and south meridian. As we have seen that dissimilar poles attract, and like poles repel each other, the pole of the needle which we call the north pole, and which is attracted to the north,

should be called the north seeking pole, and the other pole of the needle the south seeking pole.

260. The magnetic needle, while pointing in a generally north and south direction, as has been stated, does not lie in the line of the true meridian, except in a very limited number of localities, and its error is not by any means uniform, but varies, both as regards amount and direction, east or west of the true meridian. This declination, as it is called, is not stationary, but changes in the same locality, sometimes being as many as 20° away from the true meridian.

261. Another peculiarity which pertains to the magnetic needle is an inclination to dip, or point downward. The cause of this will be readily understood by an examination of Fig. 46, where the circle represents the earth with its magnetic poles at N and S. A compass needle at A would be attracted in the direction of the dotted line A N, being in the northern hemisphere, while a needle at B would be attracted in the line B S. and at the magnetic equator E the needle would remain in a horizontal position because subject to equal and opposite attractions; while at N or S the needle would point directly downward. This effect is known as the dip or inclination of the needle.

262. We may test a bar of iron to learn whether it is a magnet by placing it at right angles to the needle, at its center of motion. If this does not change the needle's position, the bar is not a magnet. But if the needle revolves right or left there is magnetism in the bar; and if the north end of the needle is attracted to the bar, that end of the bar shows opposite or south polarity, while a reverse attraction will show reverse polarity.

263. The power of attraction and repulsion may be communicated to a piece of negative iron, by contact, or even by induction, if the magnet is a powerful one. In the case of the compass needle such an effect would be quite feeble; but with

a more powerful primary magnet better results may be obtained.

264. If the piece of metal so magnetized be of very soft, pure iron, it will lose its power of attraction and repulsion at once on being removed from the neighborhood of the primary, or inducing magnet; but if it is of hard iron or steel it will retain more or less magnetic power.

265. Now, for want of a better method of illustrating this peculiarity, as we have no magnet of greater power than the needle, let us test the earth for a primary.

*Experiment 1.* For this experiment we will need some soft iron filings, a bar of hardened steel or even a piece of gas pipe, which is quite hard iron. Hold this level, in an east and west position, and strike one end a smart blow with a hammer. Now dip it in the iron filings and we shall find it has little or no magnetism, at least in its length. Now point it downward at an angle corresponding to the latitude where you are, so as to point to the actual north magnetic pole as nearly as possible, and strike the end of the bar, as before. You will find that the bar has acquired a quite perceptible amount of magnetism; that either end will attract the iron filings, tacks or other bits of iron, and that the phenomena of attraction and repulsion will be shown by bringing it near the compass needle.

*Ex. 2.* Now, having marked the end which attracts the south end of the needle with paint or chalk as the N pole, we again point it to the north pole of the earth, but in a reversed position, and strike it again as before. On testing for magnetism we will find that the particles of iron adhere as before, but what we marked as the N pole of our magnet has become the S pole, and repels the end of the needle it attracted before.

*Ex. 3.* Now we will communicate this magnetism to a second magnet by contact. Draw the blade of a pocket knife slowly over the end of the bar several times, but always in the

same direction—say from hinge to point. It will become a magnet in a limited degree, capable of picking up the iron filings. A knitting or darning needle may be treated similarly, with the same result.

*Ex. 4.* Magnetize two knitting needles in the above manner, and balance them by thrusting their ends through bits of cork. Mark the N and S ends of each with thread, and float them in a basin of water. The similarly marked ends will repel each other, and the dissimilar ends will eventually come together, and the combined needle will cease to point north and south, if they are equally charged.

## CHAPTER XII.

### TERRESTRIAL MAGNETISM CONTINUED.

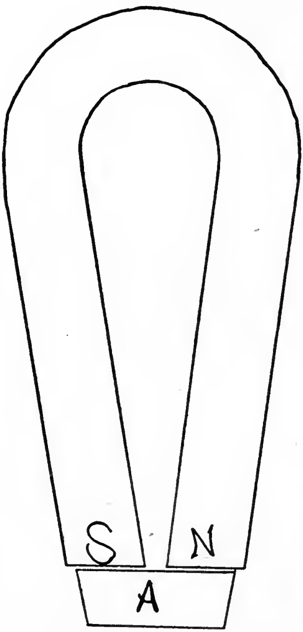



Fig. 47.

HORSE-SHOE MAGNET AND KEEPER.

266. Magnetism then may be obtained, as we have seen, direct from the great source of terrestrial magnetism, and may be communicated from one recipient to another by induction, with or without actual contact. The less the distance at which this induction takes place the stronger the inductive action; and again, the stronger the inducing magnet, other things equal, the more marked the effect.

267. Magnets are commonly either of the bar form, or the horse-shoe form. The latter is preferable for some purposes, and more readily made to retain its magnetic strength. When not in use a piece of soft iron, called a keeper or armature is laid upon the two ends of the horse-shoe, completing the magnetic field or circuit, and preventing waste of the magnetic properties of the magnet.

268. A horse-shoe magnet in outline, is shown in Fig. 47,

where N represents the north seeking pole, S the south seeking pole, and A the armature. If this magnet is suspended by a fibre of silk or thread without any twist, it will settle in the magnetic meridian.

269. A bar magnet, shown in Fig. 48, is simply a bar of magnetized steel, the poles of which, being separated by the length of the bar, cannot be short-circuited by a keeper as readily as the horse-shoe form. The bar magnet, however, has this advantage over the former shape, that in all experiments where a single pole is required, the opposite pole will not interfere because of its distance.

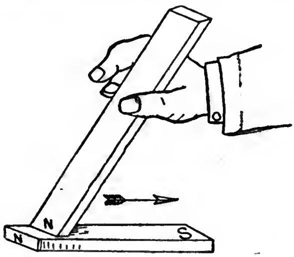



Fig. 48.

MAGNETIZATION BY INDUCTION. SINGLE TOUCH.

270. It is impossible to create a magnet with but a single pole. If we break a magnet in two we will then have two magnets, each with a north and south pole; and this process of dissection may be carried to the smallest division, without altering the result—there will always be a north and a south pole to every fragment.

271. Even if we magnetize the ends of a magnet with the same polarity, we will find at the centre of the magnet—precisely in the centre, if the amount of induced magnetism is equal at the two extremes—a pole of the opposite polarity. If the extremes are both of north polarity, the centre will be of south polarity, and the reverse.

272. It is possible to induce magnetism in a piece of steel so that there will be several north and several south poles in its length.

*Experiment.* Procure a heavy watch or clock mainspring, wind it into as close a coil as possible, and fasten it with a wire. Any watchmaker will do this for you. Now magnetize the flat circumference by touching it to the pole piece of a direct current dynamo, being careful not to turn the coil around—touch only the outer ring of the coil. After removing the coil, turn it so as to bring the magnetized face away from the dynamo, and touch the opposite face on the other pole of the machine. Now, when you uncoil the spring you will find, by testing it with a compass needle, several north and several south poles in the spring. The same result may be arrived at by touching a bar of steel with alternate N and S poles of a magnet at occasional points in its length.

273. There are several methods of communicating magnetism to steel or iron by induction. If the inducing magnet is of sufficient strength actual contact is not essential. We have seen how the earth's magnetism is communicated through thousands of miles of intervening soil, rocks, etc., rendering steel and hard iron permanently magnetic; but actual contact, under similar circumstances is far more effective, and a frictional contact is even still more so.

274. These methods of rubbing contacts are called touches. Fig. 48 shows the method known as the single touch. The body to be magnetized is lain upon a table or bench, the magnet is drawn lengthwise on the surface to the opposite extremity, and at S is raised some inches away, carried through the air, again drawn along the surface in the direction of the arrow, and again raised as before. This operation is repeated several times, always maintaining the method described. The bar will be found to have accepted, and will retain an amount of magnetism proportioned to the capacity of the inducing magnet and the fineness of the steel in the induced.

275. Another method consists in the use of two bar magnets, their opposite poles touching the bar to be magnetized at its centre, then drawing them to its extremities. In this method each magnet influences but half of the bar. The north pole of the inducing magnet moving for instance to the right, the south to the left. This is called the divided touch.

276. A third method is known as the double touch. Remove the armature of the horse-shoe magnet shown in Fig. 47, and holding it in a fixed position on the bar, slide it backward and forward from end to end, without removing it, except to treat the next side of the bar, which in turn is to be rubbed on all four sides. When the bar is sufficiently magnetized the horse-shoe should be brought to the centre of the bar, and then removed.

277. We have now demonstrated that there is a magnetic influence exerted in certain directions which is strongest at

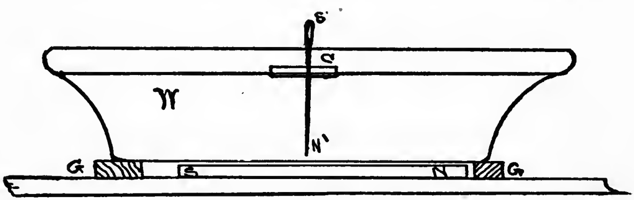



Fig. 49.

LINES OF FORCE.

the two poles, and decreases as we recede toward a point midway between them. The space in which this influence is shown to exist is known as the magnetic field, or field of magnetic force, and appears to be made up of curved lines which radiate from either pole, and seek to join.

*Experiment 1.* Lay a horse-shoe magnet on a sheet of

paper, and strew over it a quantity of black sand—which is an iron ore—or iron filings, and these will form a curved bridge between the poles, acting the part of an armature, and thus closing the magnetic circuit. Now raise the magnet, which will carry some of the filings with it, and place the armature above the filings, connecting the poles, when the filings will many of them fall, for the solid armature robs the lower part of the magnet—being the better conductor—of its magnetism, by shortening the curves of the field of force.

*Ex. 2.* Magnetize a sewing needle, S′ N′ Fig. 49, and thrust it through a thin slice of bottle cork, C. Into the glass dish, W, which is supported on a table by a couple of pieces of wood, G G, pour enough water to bring one end of the needle near the bottom of the dish, when floating. Now, having previously magnetized a short bar of steel—a darning needle will answer if well charged—place this in the space under the dish, when the point of the needle, N′ S′, will be attracted by one end of the bar magnet, and repelled by the other, and will move in a curve through the water. Reverse either needle and the movement will be in the opposite direction.

278. We learn from all these peculiarities of the magnetic field that the tendency is to shorten the bridge or armature connecting the two poles, and thus make this as perfect as possible; and that the strongest magnetism is manifested when the armature covers the greatest amount of surface at the two poles.

279. We can cause the magnet to leave an indelible map of these lines of force by either of two methods.

*Experiment 1.* A sheet of lightweight card board is first coated with a thin solution of paraffine wax, and thoroughly dried. Arrange the magnet so that the sheet will rest on some independent supports, directly above, or even touch-

ing the magnet. Now sprinkle some fine iron filings on the card board directly over the pole or poles of the magnet. By lightly tapping the card board the filings may be made to form in curves, showing the direction of the lines of force. When these are perfectly formed, melt the wax by bringing a hot flat iron near the card board, the heat from which will fasten the image.

*Ex. 2.* Coat a plate of lightweight glass with a thin solution of white shellac in alcohol. Treat this as before, and you will have either a photographic negative from which to print, or a lantern slide, at will.

279. In both the above experiments the jarring or tapping of the plate should be done as gently as possible. Striking

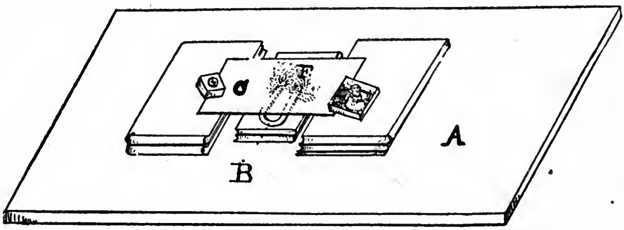



**Fig. 50.**

MAGNETIC FIELD OF FORCE.

it with a piece of light copper or brass wire—not iron— is a good method of provoking motion in the iron particles.

280. Fig. 50 shows an arrangement which is suggested as convenient and easy of attainment for these two experiments. On a table, A, arrange the horse-shoe magnet, B, at such a height that the sheet of paper or glass plate, C, will be held in place by resting on the magnet, its edges held firmly by weights or the books on either side. Now having formed the figure by gently jarring the filings, without dis-

turbing them, bring the hot iron as near as possible to the surface. The melting wax will imprison the filings, and when cold will preserve them for future use. The iron should not be hot enough to burn the card board or crack the glass.

281. A little ingenuity will enable the experimenter to obtain the form of the field of force at any angle, and with various combinations of similar and opposing polarities.

282. Combinations of two or more bar or horse-shoe magnets, placed with their faces opposite and their similar poles together, are possessed of more magnetic strength than the single magnets, and the horse-shoe magnets so arranged are the strongest, for the reason, as suggested (267), that the field of force is short, and consequently concentrated.

283. The readiness with which a magnetizable body receives magnetism—or is charged with magnetism—is proportioned to its purity and softness; and its readiness of demagnetization is in the same ratio; while the harder and better the steel the more difficult is the magnetization, and the more retentive it is of the magnetic properties.

284. Hitherto only iron and steel have been mentioned as capable of being made magnets. Nickel, cobalt and manganese possess, limitedly, the same capability. Metals of this character are called Paramagnetic, and are attracted by the poles of magnets. There are other substances, among which are phosphorus, bismuth, zinc and antimony, which act in a contrary manner, being repulsed by magnets. These substances are known as Diamagnetic substances.

285. A very close relationship exists between magnetism and electricity, and the latter enables us to produce much more powerful magnets than we have thus far considered.

## CHAPTER XIII.

### ELECTRO-MAGNETISM.

286. We have thus far mentioned only the phenomena pertaining to the inherent magnetism of the earth. Until the discovery by Oersted, in 1820, that a magnetic needle was sensibly affected by the proximity of a charged electrical conductor, only the natural magnetism of the earth was known. Arago and Davy almost simultaneously made the same discovery, independently.

287. This fact developed into the electro-magnet, and proved of untold value, not only to science, but to humanity at large. It is the basis of nearly every practical use of electricity. The telegraph, telephone, electric power, electric light, all forms of bells and electric alarms, and many other applications of electricity to commercial and domestic use, would be almost impossible without this particular development of electrical energy.

288. The construction of an electro-magnet will be understood by reference to Fig. 51, which represents a coil of insulated wire wound on a bar of iron or steel. A current of electricity along this wire is compelled to traverse its entire length to reach the negative pole of the battery. The result of this action is to set up a magnetic field and develop magnetism in the bar. This, as we have seen, will be either permanent, if the bar is of steel, or not, if of soft iron, when the current is withdrawn from the coil. The battery sends a current along the wire several times around the bar, N S, producing a magnetic field. The lines of this are shown by the smaller arrows, moving outside from N to S, and through the magnet from S to N.

289. The intimate relations existing between electricity,

magnetism, heat and light, as shown by scientific investi-

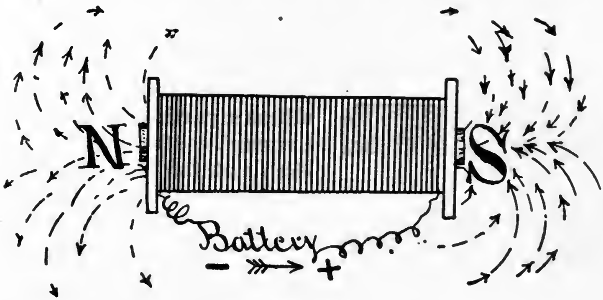



Fig. 51.

AN ELECTRO-MAGNET.

gation since Oersted, have demanded new theories to account for later phenomena.

290. Ampére was the first to offer an hypothesis to account for the cause of magnetism in an electric field. He assumed that in all bodies capable of magnetization the indivisible particles have closed electric circuits, in which currents are continuously flowing; and that these neutralize each other because of their many different directions, but that the action of an electrical or magnetic field will so rearrange these molecules that the circuits will all lie parallel, and the currents will all flow in the same direction. This theory is to-day quite universally discarded by scientists.

291. Ewing, Hughes and Weber are quite agreed that the ultimate particles of magnetizable matter have polarity, and that these lie at all conceivable angles to each other, in a normal condition—that when these are disturbed by an electrical influence they assume polarity as a whole, and that

this result may be made more certain and rapid by mechanical agitation of the molecules, through jarring the metal while under electrical influence.

292. This hypothesis is illustrated in Fig. 52, A and B. The former representing the ultimate particles of matter in thorough confusion as to position, and the latter showing their assumed position when polarized. This figure of the particles is used as being convenient for illustration, but is not to be considered as an attempt to represent their actual form.

A

B

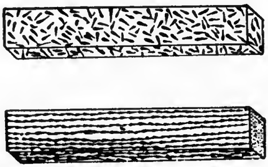


Fig 52.

(*a*) UNMAGNETIZED ATOMS.
(*b*) THE SAME MAGNETIZED.

293. The attraction existing between opposite polarities, it is assumed, brings these into line as shown, and as each polarity in the chain neutralizes the next, the polarity of the magnet is only shown at the ends of the bar, where there is no neutralization. Again, the mutual repulsion of similar polarities aids to keep them in linear form.

294. *Experiment.* Procure a tube, a lamp chimney, the ends of which can be made water tight by plates of glass. Fill this with water in which some finely powdered magnetic oxide of iron is placed. On shaking this so as to throw it into a muddy condition, it will be nearly impervious to light, but on being magnetized suddenly a flash of light may be seen. This is caused by the particles arranging themselves in the form assumed by the theory. Fig. 52.

*Ex. 2.* Take a square bottle, to the bottom and top of which fit a piece of wood as shown in Fig. 53, which will

serve to keep the wire from falling off. Having filled the bottle, as above, and firmly corked it, wind it with a quantity of insulated wire, a b, with a battery in circuit. Now

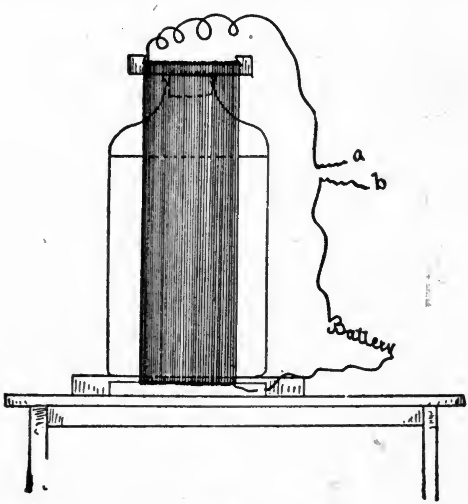



Fig. 53.

ATOMIC POLARITY.

shake up the mixture, and close the circuit at a b, and a flash of light will be seen through the sides of the bottle.

295. When a current of electricity traverses a conducting wire which lies along a magnetizable substance a field of force or attraction may be shown to surround the conductor by sprinkling iron filings on it. In Fig. 54 a wire is shown carrying a current of electricity in the direction of the

arrow through a sheet of paper. If, now, we scatter the iron filings around the wire where it comes up through the paper, we will see them assume something the form shown by the arrows.

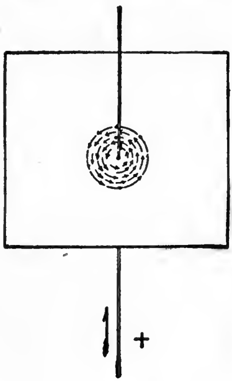


Fig. 54.

MAGNETIC ATTRACTION OF AN ELECTRICAL CURRENT

296. These curves of force are known as magnetic whirls, and not only have the direction shown around the conductor, but progress along it in the direction of the current, in a spiral. This motion is indicated in Fig. 55, where a current is assumed to be passing along a wire surrounded by magnetic whirls. These whirls are here shown to be moving in the direction of a left-hand screw, or opposite to that of the hands of a watch. Were the current in the opposite direction this movement would also be reversed. Consequently the polarity of the magnetic whirl is dependent on the direction of the current producing it. The electromagnet in Fig. 51 would show opposite polarity with a reversal of the current direction.

297. The magnetic polarity thus produced we now see is dependent on the direction in which the current flows. The whirls of the lines of magnetic force, set up by a current flowing from the observer, will always have the direction of the hands of a clock. In connection with this, Faraday's rule will be of service. Imagine you are facing the conductor, and swimming with the current, near a magnetized needle. The north end of the needle will be deflected to the left. If the current passes around the needle from end

to end, and the swimmer is facing the needle from below, the north is still deflected to his left. This rule is invariable;

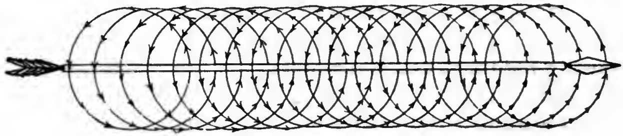


**Fig. 55.**

MAGNETIC WHIRLS.

and the fact, as we shall learn by and by, is of the highest importance in applied electricity.

298. The amount of magnetic attraction developed in a coil is dependent on several factors:

*a.* The amount of current flowing,

*b.* The number of turns of wire, and

*c.* The size of the conductor,

but there is a limit to the magnetization of any coil, which is known as the saturation limit or saturation point. Up to that point an increase in the amount of current will increase the magnetic power of the coil, but with the same current we may increase the magnetism by increasing the number of turns of wire until we reach the limit of saturation.

299. If, for instance, we have a current of one ampere flowing through a single turn of wire, around a bar of soft iron, and we have developed enough magnetism to lift a keeper or armature weighing one ounce, then with one-half the amount of current and two coils around the bar we would obtain the same result; and with three turns of wire we would require but one-third the current to develop the same lifting power in the bar.

300. From this fact has arisen the term ampere turns, as

applied to the number of times the wire is carried around the spool.

301. Hence it is necessary in computing the number of turns to know the amount of battery which is to be used; or knowing the turns and the battery, to know the size of wire to be used. If the e. m. f. of the battery is high, and the current low, then more turns are necessary, and if the battery has high amperage, then fewer turns and coarser wire may be used.

302. There is an advantage, where the electro-magnet is to be rapidly charged and discharged, in making the coil short and thick, but where a long, strong action is required, the longer magnet is better.

303. The reason for this is that a certain time is required to set up the magnetic action, and time is also required to clear out the magnetism after the current is cut off; and the shorter the coil the sooner the charging and discharging take place.

304. There is, however, a limit to the number of turns, or rather to the diameter of a coil, to obtain the best results. When the iron core is one-third the diameter of the entire coil, other things equal, the best results are obtained, because as we get farther away from the core the influence of the turn is weakened, and we are also cutting down the current by an increase of the resistance through the useless length of wire. The law of inverse squares, 206, is to be remembered.

305. The magnetic phenomena which may be developed by electricity are similar to those which pertain to the earth's magnetism; but the two differ in some important particulars. The earth's magnetism is a permanency—that of the electro-magnet is capable of change, of increase or decrease, of being set up or discontinued at will, and may be made to show polarity in any direction regardless of the earth's polarity.

306. It is stated that a properly made horse-shoe electro-magnet—that is a bar of soft iron bent in the shape of a horse-shoe, covered with wire in the proportions given in 304—the core being one foot in length and an inch in diameter, having a current of 24 amperes sent through it, will hold a keeper weighing from 60 to 80 pounds. Electro-magnets have been made of sufficient strength to hold a ton of weight.

307. While we may compel an electro-magnet coil to maintain a position at variance with the earth's attraction, if left free to move we will always find the tendency to settle in the magnetic meridian, as in the case of the compass needle. And the polarity of an electrical solenoid may be made to show the same inclination.

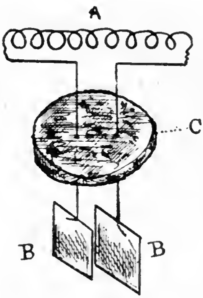


**Fig. 56.**

POLARITY OF A SOLENOID.

*Experiment.* Procure a small plate of copper and one of zinc, B B, (sheet metal will answer every purpose) attach a wire to these, having first made an open coil as shown in Fig. 56, A. These plates are made to float, by means of a disc of cork or wood, C, in a tumbler of dilute acid, such as table vinegar. The current will be set up, and flow from the copper, through the open coil to the zinc. This coil will settle in a north and south position. The effect may be increased by placing an iron wire in the coil, A, thus changing it from a helix to an electro-magnet proper. The iron core serves to concentrate the lines of force instead of allowing them to dissipate in the space surrounding the coil.

308. The field of force of a magnet is said to be made up of lines of force. There are no such lines in reality, but in order to compare the strengths of magnets, and to be enabled

to know the strength of any magnet, a system of measuring them is necessary. This method of measuring the lines of force is based on the amount of repulsion or push which one magnet exercises when placed in the field of another magnet. The unit of this force is called a dyne, and is such a force, acting upon one gramme weight during one second of time, as will move that mass one centimetre of distance.

309. The lines of force are estimated on the above basis. If, for instance, a unit pole placed in a given field experiences a force of five dynes, the field is said to have five lines of force to the square centimetre; if the force experienced is twenty dynes the field is said to have twenty lines of force to the square centimetre.

310. The units to which all other quantities may be referred, are called the C. G. S., or Centimetre, Gramme, Second, units, and form a system of measurement known as the C. G. S. system; and the dimensions are: Length—the Centimetre; Mass—the Gramme; Time—the Second. From these three fundamental units all other units which we shall encounter are derived.

311. Fig. 57 is intended to more definitely illustrate Ampére's artificial memory, or rule. The diamond shaped needle is within the coil of wire, the full lines of which are assumed to be the layers over the top, and the dotted lines the other half of the ampere turns. The Swimmer is supposed to be facing the needle and going with the current. Attached to the needle is a pointer, which, as the needle is deflected, shows the direction, which is always to his left. In this case, to the west. Were the current reversed, the man would have also to reverse, and the north end of the needle would be deflected to the left, which would then be east.

312. Another simple method by which to remember these deflections due to current is given. Place the right hand,

palm down over the wire through which current is flowing, the open fingers pointing in the direction of the flow. The thumb will point in the direction the north of the needle will be deflected.

313. The needle being hidden the necessity of the pointer will be at once apparent. In order to get an exact result it is necessary that the coil should be placed in the earth's magnetic meridian before the current is sent through the coil. To place the coil in this meridian—that is, in a north and south position—the pointer must rest over the zero of the scale; and as the needle is influenced by the magnetism of the solenoid, the pointer will move to the left, if the needle is deflected in one direction, and the reverse with a needle movement in the contrary direction.

314. The tendency of the needle under such influences is to place itself at right angles to the north and south magnetic lines of the earth; and a sufficiently strong current will always accomplish this. The east and west position is the limit, because at that point equal and opposite magnetic forces meet.

315. We now have the fundamental principle of the Galvanometer, the Voltmeter and the Ammeter, as well as the needle telegraphs of Cooke and Wheatstone and many other minor applications of electro-magnetism.

## CHAPTER XIV.

### GALVANOMETERS.

316. The first galvanometers were known as multipliers, from the fact that the many coils of which they were com-

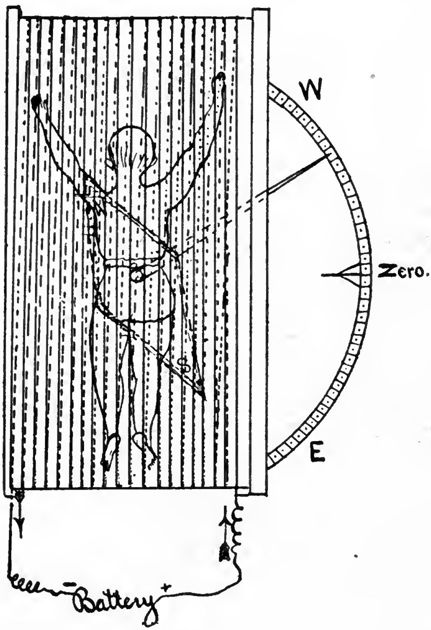



Fig. 57.

AMPERE'S RULE.

posed multiplied the result of the magnetic action. Exper-

iment soon showed that doubling the amount of current did not double the amount of deflection—that is, if a given current induces a deflection of 10°, a current of twice the amount through the same coil does not necessarily deflect the needle twice the number of degrees.

317. The reason for this is plain, when we remember that the separate turns of the conducting wire cannot all be placed at equal distances from the needle, nor maintain their distances as the needle moves. And again, the farther

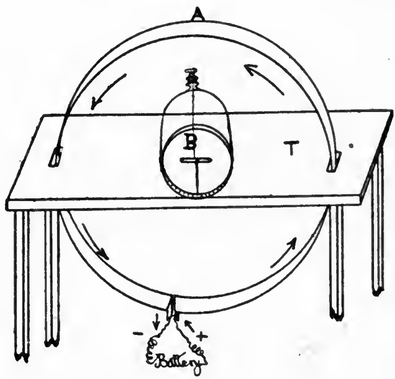



Fig. 58.

TANGENT GALVANOMETER.

the needle is deflected, the farther it is away from the strongest part of the influencing field. Of course the nearer it approximates a position at a right angle to the coil the less effect the coil has upon it.

318. To obviate this difficulty several forms of galvanometer have been constructed, the first of which, known as the Tangent galvanometer, is shown in Fig. 58.

319. A circular ribbon of copper, A, is carried almost completely around the needle, B, the latter being extremely short, and suspended by a thin, untwisted fibre of silk, while the former is an inch wide and 1-12 of an inch thick. The needle, even if placed at right angles to the ribbon, would still be in a strong magnetic field. The ends of the ribbon are separated by a small fraction of an inch, and wires lead thence to the battery. With such a galvanometer the deflections are nearly proportioned to the strength of current. This instrument was the invention of Pouillet, a French electrician.

320. A second form of tangent galvanometer is that of Gaugain, in which the coil, something the shape of a lamp shade, could be made to approach to or recede from the short needle which traversed a horizontal disc supported on a table. In whatever position the needle was placed there was always a current producing a field of force tending to deflect it proportioned to the strength of the current. These were formerly used quite extensively by telegraph electricians for testing lines, but have gone into disuse.

321. A form of instrument. called the sine galvanometer, is so arranged that the coil may be turned, following the needle, thus keeping it in the strongest portion of the magnetic field, until no further deflection is shown—the needle standing parallel to the coil, which is vertical. The horizontal scale then shows through how many degrees the needle has moved; and the strength of the current is directly proportioned to the sine of the angle measured on this circle through which we must move the vertical coil from the magnetic zero position to overtake the needle at rest.

322. The sine of an angle is the perpendicular let fall from the extremity of one radius upon another. C D, Fig. 59, is the sine of the angle C N A, or the arc N C. A deflection of a needle, N S, would carry the pointer from the line A B either toward N or S, and it is evident the sine C D

would lengthen in direct proportion to increasing current strength. The tangent of an angle or arc is a line projected from the circumference of a circle, at a right angle to a given diameter. Thus in Fig. 59, N E, is tangent to the several angles made by the intersection of the radii shown. B O is also tangent to the angle B A C and the arc B C.

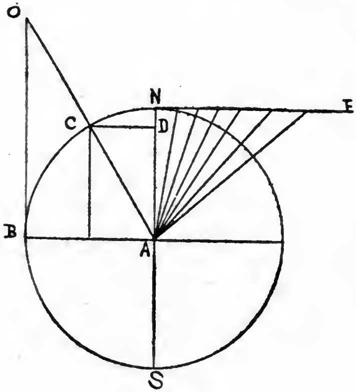



**Fig. 59.**

SINE AND TANGENTS.

323. It will be evident from a glance at the figure, that while the deflection of the needle is comparatively accurate through a few degrees, the enfeebling of the magnetic influence as the needle moves out of the field increases rapidly, until at last a parallel would be reached when the needle had moved through an arc of 90°. The current intensity is directly proportional to the tangent of the angle of deflection.

324. Another form of galvanometer which, with those mentioned, has fallen largely into disuse because of better systems, is known as the differential galvanometer. We have seen that the deflection of the needle with the same current, is either east or west, governed by the direction of the windings of the coil.

325. In a differential galvanometer two coils surround the needle, both being brought together at the battery, and attached to the same pole. These coils are precisely the same as to length, size and material—in short, as perfect

electrical duplicates as possible. One of these coils is connected to the resistance to be measured, and the other to the coils of a rheostat. The resistance of the rheostat is varied until the needle is brought to zero. The unknown resistance then exactly equals the known resistance of the rheostat.

326. The rheostat coils in Fig. 60 represent but a small portion of an ordinary box of resistances. There are several such combinations, commencing usually with a row in which, to illustrate, a would have a resistance of 1 ohm; a′ would have a resistance of 2, the third of 3, and the fourth of 4 ohms. Then as the block stands the resistance measured from one extreme to the other would be the sum of these four, or ten. A second block would have for its series, 100, 200, 300, 400, and the third block 1000, 2000, 3000, 4000. These several blocks are arranged in a box, all connected so that the whole or any part of the resistance of the several blocks may be measured at once.

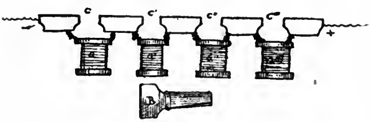



**Fig. 60.**

A SIMPLE RHEOSTAT.

327. A split plug, B, (split in order to make it fit more snugly) if inserted at c or c′, c″ or c‴, would cut out the corresponding coil beneath it. If for instance, the coils represented 1, 2, 3 and 4 ohms respectively, and if a plug were inserted at c″ the block would only measure 7 ohms, for the current would pass across the plug instead of through the coil; and now if a second plug were placed in c′ that coil would also be cut out, and the block then would measure but 5 ohms.

328. In this form of rheostat as many plugs are required as there are coils, and a resistance of from one ohm to the

full capacity of the rheostat can be obtained by their use.

329. A Differential Galvanometer is shown in Fig. 61. The instrument is supposed to be wound with several turns—of which but two are shown—around the needle. When used, the needle is placed in the magnetic meridian. A battery, B, will, when the key is closed at K, send out a current which will divide at D, inversely as the resistances through which it passes—the coil C and the rheostat R, on its way to earth at G. Starting with the plugs all out of R, we find the needle is strongly deflected to the east, which tells us that the resistance R is greater than that of C, and by inserting plugs we reduce the deflection until the needle settles in the magnetic meridian. We now count up the resistances of the unplugged spools, and this sum will show exactly the resistance of C.

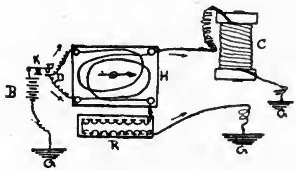


Fig. 61.

DIFFERENTIAL GALVANOMETER.

330. We have learned, 288, that an ordinary coil of wire around a spool develops a strong induction, and this action is a source of error in spools used for measuring resistances—standard resistance coils. To avoid this the wire for such purposes is wound on the spool in a parallel loop, so that the incoming and outgoing current of the coil, being opposite in their inductive effect, neutralize the abnormal resistance. Such coils are called non-inductive.

331. We may greatly increase the sensitiveness of a galvanometer by means of what is known as an astatic needle. It consists of two needles fairly similar as to their magnetic power and otherwise, both being firmly attached to the same

stem, one above the other, reversed. Thus there is a north and south pole at each extremity of the combination.

332. The stem is suspended so that the combined needle can settle in the magnetic meridian, by a silk fibre having no twist, which is more delicate than suspension on a vertical point. Because of the opposite polarities at the extremes of the needles the earth's attraction has but a feeble influence, and a very much less current induction will deflect the needle. Were the two needles precisely similar in every respect, the earth's magnetic influence would be perfectly counteracted, and the needle would come to rest in one position as well as another.

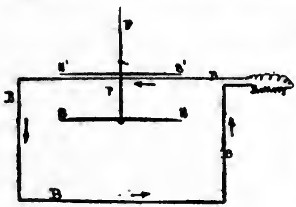


Fig. 62.

ASTATIC GALVANOMETER.

333. An inspection of Fig. 62 will make this action better understood. A current from the battery is flowing around the circuit, made up of many coils of which B is the representative. The two needles N S, N′ S′, rigidly fixed on the shaft P, must necessarily move together. F represents the fibre of suspension from the glass shade which covers the instrument. The needle N S is suspended within and about the centre of the coil, while N′ S′ is placed above the coil. The effect on the two needles is the same as we know by Ampére's rule, 311, and while the earth's magnetism is much enfeebled, the induction effect of the current traversing B B B B is greatly increased.

334. The current with which measurements are made may be of such force that it is impossible to read the angles accurately. In such conditions the remedy is to permit but a part of the current to flow through the coils. This is done

by means of a by-path around the coils through which a portion of the current passes without affecting the needle, such paths are called shunts, and their exact resistance, being accurately known, the amount of current they thus carry is readily calculated.

335. Fig. 63 will illustrate the theory of the shunt. The total current from the battery, B, is represented by S, flowing through the line to A, and there being but one path for it to return it passes through the galvanometer G, and back to B. $S^2$ $S^3$ $S^4$ $S^5$ are resistances of varying amounts, which are open, as shown, but either of which may be connected by inserting the plug P into one of the openings. The current then will divide inversely, as the resistances of G and whichever of these are plugged in.

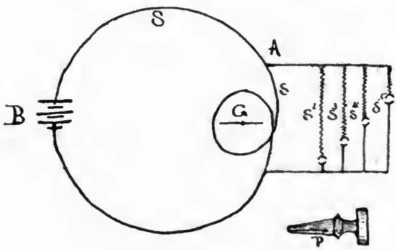


Fig. 63.

GALVANOMETER SHUNTS.

336. In another form of galvanometer, in place of a pointer traversing the arc of a circle, a beam of light is made to show on a scale and the deflection of the needle is greatly multiplied. This instrument is called a reflecting galvanometer. The magnet in this instrument is extremely light and short, and suspended by a delicate fibre in the middle of a large, powerful coil. Upon the face of the needle is a very small mirror, placed at such an angle that a ray of light projected upon it from a lamp or candle is thrown back upon a scale a few feet away. This beam of light is thrown upon the mirror, which is generally plano-convex, through a fine slit in a screen at the lamp, and the bottom of the mirror,

being thrown slightly forward, the beam is reflected back to the scale, which is just above the source of light.

337. The extremely short needle under all circumstances is within the magnetic field of the large coil, so that the tangents of the deflections are directly proportional to the strength of current by which they are produced.

338. Fig. 64 will show the general principle of a mirror galvanometer. A coil surrounds the small needle on the front of which is fixed the mirror A. A beam of light C, from the lamp B, is reflected back on the line D, to the scale E. By this arrangement a pencil of light is made to enact the role of a pointer several feet in length, without the hindrance otherwise due to gravity, and the needle itself, scarce half an inch in length, weighs hardly a couple of grains. In some forms of reflecting galvanometers, of which there are several, a lens is used for the better formation of the light image on the scale, and a fine platinum wire is also sometimes used to cast a shadow in the middle of the light spot, to insure still greater accuracy. The sensitiveness of the needle is varied by lowering the damper magnet, shown detached at M, and which can be revolved to bring the needle to zero, in the coil. The astatic needle may also be used in reflecting galvanometers. For use on water the magnet is suspended in such a way from top and bottom that the needle can only rotate in a horizontal plane.

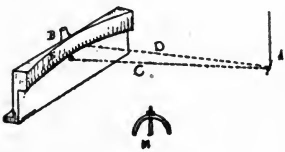



Fig. 64.

REFLECTING GALVANOMETER.

339. While the reflecting galvanometers, of which there are several, but all embodying the same general principle, are extremely accurate, the necessary delicacy of adjustment, and their inconvenient size renders them to an extent unavailable for general commercial use. Accuracy and ease

of handling are combined in a combination usually known as the Wheatstone bridge or testing set.

340. This combination consists of a battery, a galvanometer, and a box of resistance coils. The principle upon which it is founded is the well known law that the potential of any current is reduced by its passage through any resistance, in proportion to that resistance. By means of three sets of resistances which are adjustable, a fourth unknown resistance may be ascertained.

341. The principle of the Wheatstone bridge will be readily understood by an examination of Fig. 65, which is a diagramatic representation of that instrument.

342. The various lines from the battery are multiple connected throughout the instrument. At B, C and D are placed boxes of adjustable resistances. The unknown resistance, which is to be measured, is connected between S and A. The wire S R runs through the galvanometer. A double key, not shown, closes the battery circuit and also the galvanometer circuit, which are both normally open. When this key is closed there are several paths for the current to return to the battery; and a portion, governed by the resistance, will return via Y B C A, a portion through the path Y D S A, and if not adjusted properly a portion will flow through the galvanometer. The deflection will be east or west, according to the current direction.

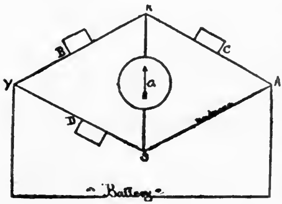



Fig. 65.

WHEATSTONE BRIDGE.

343. If the three resistances, B C D, are properly adjusted there will be no current through the coils of G, and the unknown resistance can then be found.

344. Suppose now we insert at B 10 ohms, at C 10 ohms,

and at D 10 ohms, and if on closing the key the needle is stationary, we know that the unknown resistance is also 10 ohms. But if we have 10 ohms in B and 100 ohms in C, and D requires 500 to bring the needle to rest at zero, then we find the resistance of the unknown to be C × D ÷ B, or, 100 multiplied by 500, and divided by 10, which will show the unknown to measure 5000 ohms.

345. Thus we see that when the four sides B C D and the unknown are the same, there will be no current through the galvanometer. And again, when the different resistances are not the same, if they but maintain such a relative proportion that the potential is balanced, the same result will follow.

346. If the resistance at B were 10, at C 100 and at D 500 and in place of the unknown resistance we insert 5000, the result would be the same. For the current divides at Y inversely as the resistance of the two routes Y B R, and Y D S, and as the resistance of D is 50 times as great as that of B, then 50 parts of the current pass through B with a resistance of 10, and one part passes through D with a resistance of 500, and as the same proportions exist between the resistances of the other two branches, the two currents flow on, joining at A, and return to the battery. The proportion then is written: B : D : : C : unknown, or multiplying D by C and dividing that product by B, the answer will be the unknown, when the proportions are such that the needle of G refuses to move when the key is closed. On the other hand, if these proportions are not similar, a portion of the current passes through the G coil, and deflects the needle.

347. In commercial use the most convenient form of Wheatstone bridge is one which includes the three factors, battery, resistances and galvanometer, in one portable case. The coils of the three sides are so connected that plugs are dispensed with, and the contacts are made with switch arms. This form is only useful where great exactness is not essential. There are several forms of bridges, but all depend on the principles mentioned.

# CHAPTER XV.

## PRACTICAL APPLICATION OF OHM'S LAW.

348. Reference was made in Chapter II to that law first announced by George Simon Ohm, a German mathematician, in "The Galvanic Chain, Mathematically Worked Out, 1827," showing the relations existing between current flow, electro-motive force, and resistance in a circuit. This law, named after its discoverer, may be thus stated:

349. The flow of current traversing a conductor is dependent on two factors: the e. m. f. of the source, and the obstructions which intercept its passage. "For equal resistances, it is proportional to the whole electro-motive force tending to maintain the current, and for equal electro-motive forces it is inversely as the whole resistance in the circuit." This law is usually written $C = \frac{E}{R}$, a formula in which E represents the electro-motive force of the source, R the resistance, and C the current flow; and is read: Current (flowing in the circuit) equals the electro-motive force (of the electrical source) divided by the resistance (the obstruction to the passage of the current.)

350. Whenever a metal which is attackable by an acid is brought into contact with one, chemical action takes place which develops a difference of potential, the acid having a higher potential than the metal. This difference of potential has a tendency to force a current through a circuit, and thus accomplishes work. In many respects a similarity exists between the flow of a current of electricity and that of water. The quantity and the level of either control the amount of work which they can accomplish. The term electro-motive force is defined as "the total generated difference of potential"—*Hering.*

351. If we have a number of battery cells connected up in series, and close the circuit, there is in each cell a gradual fall of potential from the film of liquid in contact with the positive element to the contact surface of liquid and negative element, and also a drop in the connecting or closing wire uniting the latter to the former, outside the battery; and if there are instruments of any kind in the circuit, there is a fall of potential there, also.

352. When the poles of a battery are open the difference of their potentials is a measure of the e. m. f. of the battery. But immediately we connect these there is a tendency to equalization between the terminals, the diminution being more rapid as the resistance of the connecting wire is less, and the reverse when it is more.

353. Now the original potential difference is reduced by two classes of resistance, that within the battery itself, and that between the outside terminals of the combination.

354. Fig. 65 will aid in understanding this difference of potential in a circuit. The diagram represents the rise and fall of potential in a battery of four cells in series, and between the terminals

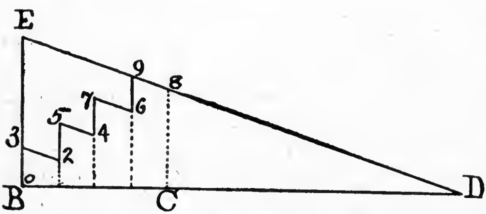



Fig. 66.

ELECTRICAL POTENTIAL.

connected by a long wire, having a resistance twice that of the battery.

355. The line B D represents the total resistance in the circuit, being the sum of the battery resistance added to

that of the connecting wire, the former represented by the portion B C, and the latter by the portion C D.

356. The potential rises from the first zinc to the acid in contact with it. It falls in overcoming the resistance offered, and on arriving at the copper is proportionally weakened, but at the second zinc it is again raised, to be partially weakened again, and so on to the positive terminal, when, there being no more accumulations, it falls gradually to the point D, which is assumed to be connected to earth.

357. If the resistance of any individual cell is sufficiently high to absorb all the current arriving at that point, there will be no delivery of current at the positive terminal; and the same would be true if the outside resistance were sufficiently high.

358. The distribution of potential (disregarding the small differences which are supposed to exist between dissimilar substances in contact), may be stated in tabular form as follows, the electro-motive force of each cell being called 3 (*Deschanel*):

| | | Potential. | | | Potential. |
|---|---|---|---|---|---|
| First Cell | Zinc | 0 | Third Cell | Zinc | 4 |
| | Acid | 3 to 2 | | Acid | 7 to 6 |
| | Copper | 2 | | Copper | 6 |
| Second Cell | Zinc | 0 | Fourth Cell | Zinc | 6 |
| | Acid | 5 to 4 | | Acid | 9 to 8 |
| | Copper | 4 | | Copper | 8 |

Connecting Wire..............8 to 0.

B E or 12 represents the whole e. m. f. of the battery; and if the external resistance were infinite, or if the poles were disconnected, the sloping lines 3, 2; 5, 4; 7, 6; 9, 8, would not be sloping, but horizontal, and marked 3, 3; 6, 6; 9, 9; 12, 12.

359. It is plain from what has been shown, that if we had a battery of 40 units and a total resistance of 10 units,

we would have the same current flow as from a battery of 100 units with a total resistance of 25 units in the circuit.

360. If with the same electro-motive force we can reduce the resistance, either externally or internally, we will increase the current flow. In the battery we can accomplish this result either by enlarging the individual plates or connecting all the positive plates together as one, and the negative as one, as we have seen, Figs. 39 and 40, and we may also reduce the internal resistance of the battery by decreasing the distance separating the elements.

361. The outside resistance may be reduced by the use of larger wire of the same metal, or by substituting a metal of superior conductivity. Having an iron connecting wire, for instance, we will greatly increase the conductivity (decrease the resistance) by substituting copper. The advantage of copper over iron in this regard is as 100 is to 16.8; and a lead wire to have as low a resistance as one of copper would require ten times the cross section.

362. The term electrical resistance having been explained thoroughly, may be succinctly defined as any obstruction which may require work to be done by an electric current traversing a circuit. The resistance, by the terms of the formula is equal to the e. m. f. divided by the current; hence the e. m. f. is the product of the current multiplied by the resistance, and the resistance is the quotient of the e. m. f. divided by the current. Thus, two factors being known, the third is readily found. 42 to 44.

363. The resistance of a wire of given material at standard temperature is governed by the cross section of that wire. In a pipe for carrying water, the larger the pipe the more water it will carry, and the less obstruction, other things equal, in proportion to the flow. The larger wire presents less obstruction to the electric flow. Again, the longer a pipe is the greater the pressure required to force the water through it, and the longer a wire is the more force

is required to overcome the obstruction due to its length. We learn then that "the strength of the current is inversely proportional to the resistance of the circuit," and "the strength of the current is directly proportional to the electromotive force."

364. Considering these two propositions it is readily seen that we may arrive at a given flow of current by different electro-motive forces or by varying resistances. Since, while the e. m. f. or potential difference remains constant, an increase in the resistance will lessen the current; and with a constant resistance an increase of electro-motive force will increase the current, it follows necessarily that both may be augmented or diminished simultaneously without varying the current.

365. If a Grove or a Bunsen cell having an e. m. f. of 1.93 volts, and a Daniell cell with an e. m. f. of 1.072 were so arranged as to give the same current flow through short, thick closing wires, and these were then substituted by long, thin wires, the current of each would be reduced, but the Daniell would show the greater effect, which is readily proven by an application of the law of Ohm. Suppose the Grove, for example, had an e. m. f., in round numbers, of two volts, with a resistance of one and one-half ohms, and its poles were joined by a conductor of half an ohm resistance, we would have a total resistance of 2 ohms in the circuit. The strength of current, C, would then be $\frac{2}{2} = 1$ ampere. Assuming that the Daniell cell has an e. m. f. of one volt and a resistance of .5 of an ohm, and we add the resistance of the closing wire, say .5 of an ohm, we will have $E = 1$ and $R = .5 + .5 = 1$ ohm. Dividing E by R, $C = 1$, as in the other instance; but if in the Grove circuit we introduce a conductor having a resistance of $3\frac{1}{2}$ ohms we would have, when added to the $1\frac{1}{2}$ ohms internal resistance, a total of $3\frac{1}{2} + 1\frac{1}{2} = 5$ ohms. Now dividing the volts by the ohms we have but .40

of an ampere of current, while the Daniell, under similar treatment, would develop 15 per cent. less current, for C = 1 divided by .5 + 3.5 ohms = .25 of an ampere.

366. In the examples 219 to 224 we had a battery of three cells, with which we learned how to vary the e. m. f. and current flow. Now we will assume that we have eight similar elements (Fig. 67). These we can arrange in either of four combinations, and thus vary both the voltage and current flow, one increasing as the other diminishes.

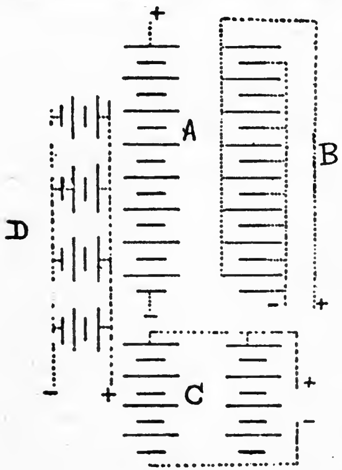



Fig. 67.

BATTERY COMBINATIONS. CLOSING WIRES SHOWN BY DOTTED LINES.

367. If we join these up in series, or tandem, as at A, we will have the highest e. m. f. and the lowest current; while if we connect all the zincs as one plate (B), and all the coppers as the other, we get the same voltage as if it were but one cell, but the internal resistance is only one-eighth what it was, and consequently we have more current at the expense of a diminished voltage.

368. Intermediate between these are two other possible arrangements. If we break the battery into two, of four cells each (C), and connect the two copper terminals as one, and the zinc terminals as one, we will have four pairs of plates of double the size of those in the series combination. Again, breaking the battery into a fourth arrangement (D), we may have four series batteries of two cells

each, which we may couple by joining the terminals as before, and we will have a battery of two pairs, with plates four times those first mentioned, or double those of the C combination.

369. Assuming that the resistance of each element is four ohms, in the first arrangement the resistance of the eight cells would be 32 ohms; in the second 0.5 of an ohm; in the third arrangement 8 ohms; and in the last, 2 ohms.

370. In a commercial line of telegraph, or an electric light system, we may materially aid the current flow by removing harmful resistances, which we have found by the aid of a galvanometer. An instance well vouched for is a marked example: An electric light plant, which originally consisted of 60 series arc lamps of 50 volts each, had so far run down as to carry less than half that number, and these not up to normal in candle power. A galvanometer test showed an enormously high resistance in the line, which was principally resident in faulty connections and unsoldered joints. When these were properly corrected the full complement of 60 lamps burned up to normal candle power.

371. The three factors in Ohm's law are thus defined, as adopted by the Chicago congress of 1893:

(*a*) The international volt is such an electro-motive force that, steadily applied to a conductor having a resistance of one international ohm, will produce a current of one international ampere, and is practically $\frac{1000}{1434}$ of a Clark's cell at a temperature of 15° C.

(*b*) The international ohm is represented by the resistance offered to an unvarying current by a column of mercury at the temperature of melting ice, 14.4521 grammes in mass, of a constant cross section, and 106.3 centimeters in length.

(*c*) The value of the international ampere, adopted by the Chicago Congress of 1893, is such a current as will

deposit 0.001118 gramme or .017253 grain of silver per second from a neutral solution of silver nitrate in distilled water. This is the practical unit of current, which is one-tenth the unit of current of the C. G. S. system of electro-magnetic units—this latter being too large for practical use. Commercially, a current capable of depositing 4.024 grammes of silver per hour.

372. We must make a careful distinction between current flow, or rate of movement, and quantity of current, the unit of quantity being a coulomb, which is defined as the quantity of electricity that flows per second past the cross section of a conductor conveying an ampere.

373. The similarity between the flow of water and of electricity will again serve to illustrate the difference between the coulomb and the ampere. Water flow is reckoned by the cubic feet per second, electricity by the amperes, or coulombs per second. One coulomb per second is one ampere.

374. If we have two or more routes by which the current may complete its course from the positive to the negative terminal, the current will be divided into as many parts as there are conductors, the amount of current flow in each division will be inversely as the resistance of that division, and the combined resistance will be much lessened.

375. We have seen how this fact is taken advantage of in Chapter XIV, in galvanometer practice.

376. Suppose we have two conductors, R R′ Fig. 68, forming the closing wire or line between the poles of an electrical source, G. If these two conductors are of the same material, length and cross section, their resistances will be the same, and the current flow through each will be the same; while the joint resistance will be only one-half what either wire separately would show; and with three such conductors, only one-third.

377. If, however, we have two or more such closing

wires, of either different metal, different lengths or different cross sections, so as to exhibit different resistances, the proposition becomes more complicated, and the amount of current flow will not be the same in each of the several

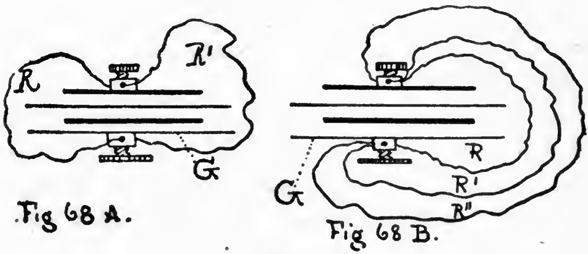



Fig. 68.

branches—the joint or total resistance of the combination, while much reduced over any single conductor of the group, will not be directly proportioned to any one wire.

378. In Fig. 68 A, the two wires R R′ are assumed to be of the same resistance. It follows as a natural sequence that the same current will flow from the battery, G, through each, and the same would be true of any number of similar conductors. Simply dividing the flow of current supplied by the battery by the number of such conductors will give the proportion carried by each.

379. Fig. 68 B represents three conductors assumed to have different resistances. Their joint resistance may be found by either of three methods.

(*a*) Find the joint resistance of either two, and with that as a new resistance find the joint resistance between it and the third, which will be the resistance sought.

(*b*) A second method is as follows: Multiply R R′ R″ together, and divide this by the sum of $R \times R'$, $R \times R''$, and $R' \times R''$.

(*c*) Divide 1 by the sum of the reciprocals of the several resistances. (The reciprocal of any number is the quotient obtained by dividing 1 by that number.) The reciprocal of 8, for instance, is $\frac{1}{8}$ or .1250, and that of 20 would be $\frac{1}{20}$, or .0500.

380. Now we will assume the following as the resistances of the three wires: Let R equal 20, R′ 30, and R″ 28 ohms.

(*a*) First process. The joint resistance to be found between 20 and 30 ohms. Dividing the product $20 \times 30$ by the sum $20 + 30$ we have $\frac{20 \times 30 = 600}{20 + 30 = 50} = 12$. We have now to find the joint resistance between 12 and 28. As before $\frac{12 \times 28 = 336}{12 + 28 = 40} = 8.4$.

(*b*) Second process. $\frac{20 \times 30 \times 28}{20 \times 30 + 20 \times 28 + 30 \times 28} \frac{= 16800}{= 2000}$

(*c*) Third process. Divide 1 by the sum of the reciprocals:

The reciprocal of 20 is .0500
The reciprocal of 28 is .0357+
The reciprocal of 30 is .0333+
.1190+

And 1 divided by .1190 is 8.04 ohms.

381. Suppose we have a circuit in which a potential difference of 24 volts exists between A and B, Fig. 69. At A the circuit is divided, one portion of the current passing through a resistance of 8 ohms, the other through a resist

ance of 6 ohms, the branches uniting again at B. The current flowing through the first wire will be $\frac{24}{8}$ or three amperes, and through the latter $\frac{24}{6}$ or 4 amperes. Now the joint resistance of the two circuits having separate resistances of 8 and 6 ohms, will be 3.428+, which, multiplied by the 7 amperes, will give us the 24 volts with which we started, and prove the proposition.

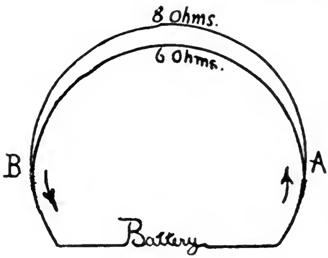


Fig. 69.

## CHAPTER XVI.

### ELECTRO-CHEMISTRY.

381. We have seen in Chapter VIII how electricity may dissolve and deposit the metal in a solution of a metallic salt, like copper sulphide. Acting upon a knowledge of these facts has enabled electricians to inaugurate an industry based on the deposition of a coating of greater or less thickness upon all sorts of metallic bases, and even upon wood or other substances, which are first made conductors by being covered with a thin film of some form of conducting dust like carbon or plumbago.

382. The applications of this form of metallic deposition include nickeling, gilding, silvering on baser metals, the facing of printing type with copper, etc.

383. This process of covering one metal with another is known as electro-gilding or electroplating. The recipient is usually a baser metal, such as brittania ware, tin, german silver or brass, and may be covered with any of the more valuable or showy metals.

384. The process differs more or less for the different metals used. In the plating of articles like jewelry, spoons and the like with gold, a solution of the metal, usually the salt generally known as the Cyanide, is used. This salt is quite poisonous, and requires to be very carefully handled.

385. The process of electroplating requires firstly a receptacle or vat for the liquid, with metal cross bars from which to suspend the articles to be treated, so arranged that these will be in one side of the circuit. Between each two rows of these articles are plates of metal which supply the losses from the solution. These plates (the positive or anode

poles) are connected to the positive terminal of the electrical source, while the cathodes connect the articles to be treated to the negative terminal.

386. Formerly batteries were used in electro-chemical work, but dynamo currents to-day are much preferred and quite generally adopted. The voltage of a plating dynamo is quite low, not usually above 4 or 5, while the current flow is of course proportioned to the resistance in accordance with Ohm's Law.

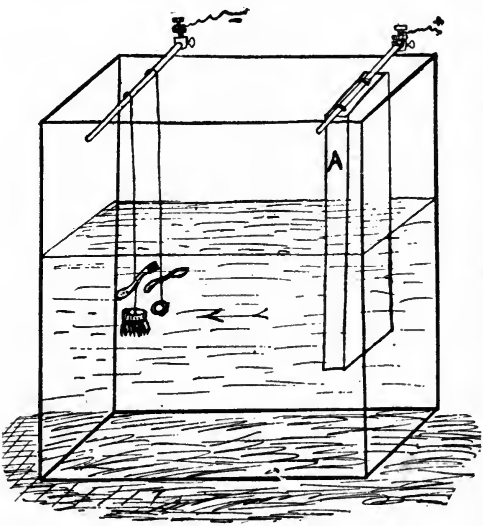



Fig 70.

AN ELECTRO-PLATING CELL.

387. In Fig. 70 we have an illustration of an electro-plating cell; for more easy comprehension this is represented as being constructed of glass. A plate of metal (A) is suspended in the cell, opposite the articles to be acted upon. This plate is the Anode, while the opposite or Cathode is represented by articles to be plated, and the metal solution, when the electrical source is connected at the terminals + and − will be disintegrated, giving up its metallic element,

which is constantly renewed by the action of the acid element upon the plate (A).

388. In the figure only one anode and one cathode connection are represented. In practice several of the latter are placed, each resting on two parallel copper rods connected to the one terminal, and between each two of these a plate of the metal is suspended similarly; so that there are alternate anodes and cathodes the entire length of the cell, which may be six or eight feet in length by three or four feet wide, and as many deep; and one is on record capable of holding over 6,000 gallons of solution.

389. The articles to be treated are carefully smoothed and polished, and must be scrupulously clean in order that good work may be done. The least particle of grease will prevent this, and touching with never so clean hands is fatal.

390. The solutions for the various metals to be deposited of course require different combinations in each case. Cyanide of Silver is commonly made use of for silvering articles of baser metals, such as spoons, forks, etc. This salt, sparingly soluble in pure water, is a salt of silver and cyanogen; the plate or bar (A) being solid silver. The bath may be a solution of some other silver salt. There are several silver salts, more or less available, as the Chloride, Nitrate, Acetate, Sulphide or Oxide. These may be, but are seldom, used, except in laboratory experiments.

391. The names of these various salts at once suggest their origin. A chloride of any metal is a combination of that metal with chlorine; an oxide with oxygen; a sulphide with sulphur, etc. Cyanogen is a compound radical, being a gas composed of one equivalent of nitrogen and two of carbon. Its salt is almost insoluble in pure water, but by the addition of a salt of potassium—the prussiate—is readily dissolved. The compounds of prussic acid—or hydrocianic acid—are very poisonous.

392. The voltage and current flow have much to do with

perfect work. These must be proportioned to the work to be done. With properly arranged current and pressure the coating is even, smooth and firmly attached. Imperfect conditions may deposit the metal too rapidly, and the plating is liable to flake off, or on the other hand the deposit may take place too slowly. The coating may be granular if too rapidly deposited, and require the intervention of resistance coils to reduce the flow of current, and under unfavorable conditions may be deposited as a black powder.

393. Again, the form of the articles submitted has much to do with results. Prominent parts of an article like points in ornamental jewelry, are apt, if much nearer the cathode than the depressions in the articles, to take on too much and too rapidly, and thus become distorted. The number of pieces or surface exposed have much to do with results.

394. What has been said applies generally to the deposition of all metals by electrolytic action. For gold plating a combination of that metal with cyanogen is used, while for nickel plating a green compound salt of sulphate of nickel and sulphate of ammonia is commonly used.

395. In plating the inside of vessels like silver cups, urns, bowls, etc., the vessel is filled with the solution, the outside of the vessel being connected to the negative pole of the electric source, while the metallic anode is suspended in the solution. In this case the anode is quite light, as the deposit is hardly more than a mere film.

396. A still more easy method of skin plating is followed for cheap work, by simply dipping the articles in a solution, when chemical action takes place, resulting in depositing the thinnest possible film of metal on the surface. This process is sometimes designated dip plating.

397. Probably no metal has more varied applications in this line than nickel. Its near resemblance to silver, its cheapness, its ability to hold its polish, make it at once acceptable and useful. An almost endless variety of applications of nickel

plating are to be seen. The hardware industries find nickel a cheap finish for beautifying all varieties of castings, from ornamental grates and stoves down to the smallest house furnishings, chains, lamps, carriage and harness trimmings, etc., etc.

398. When a greater depth of metal is deposited, the process is known as electroplating. Electroplating is of immense value to the printer. Where a large number of impressions are to be had from a page of a book or newspaper, if the type of which the page is composed were used, two results would follow—the type would become worn and have to be renewed, while the printing would be inferior. To avoid this a paper pulp impression may be taken of the type in the form. This paper matrix is then made an electric conductor by being coated thoroughly with a thin film of pulverized graphite or plumbago—often called black lead, although there is no lead in it—and this is made the cathode of an electrolytic combination, the solution being a bath of blue vitriol or sulphate of copper, into which a small amount of sulphuric acid has been mixed, and the anode being a plate of copper. When the deposit has reached the proper thickness the shell is backed by a filling of type metal, and the paper matrix is removed, leaving a perfect copper reproduction of type, cuts, etc., with the type uninjured. Within a few years even this process has been superseded, and the type setter now not only forms the line, but makes a matrix, and casts a solid line of type metal, all with one machine, doing the work more rapidly than several men could do it by the former method.

399. Copper is sometimes deposited as a finish on iron lamp posts, gas fixtures, etc., and as a base for subsequent silver or gold plating on smaller articles like locks, latches, hinges, etc. Beautiful copies of objects of art may also be made on iron by the electrolytic process. Statues have been

executed weighing two tons, and over 13 feet in height. Bas-reliefs have been copied covering 500 to 600 square yards.

400. Impure ores of copper, scrap copper, old telegraph and electric light wires in which there is always more or less solder, and copper mixed with other impurities may be purified by electrolysis, the cathode being a plate of pure copper, the bath a solution of sulphate of copper, and the anode the impure metal. The pure copper replaces the exhaust from the bath, and the impurities fall to the bottom of the tank. Recovered copper thus deposited is extremly free from impurities, and is us ed for electrical conductors where low resistance is required.

401. On removal after the articles are treated, they require to be cleaned and polished. In some cases the article requires pretty severe treatment to bring out the desired result. A dead, lusterless finish may be desired in parts of an ornamental article, while other portions require to be highly polished. After the whole piece has been polished up to a certain point by revolving brushes of some soft metal like brass, the portions requiring a reflecting polish are treated with steel burnishers or stone polishing tools.

402. A something similar combination is used to measure the amount of current flowing along a given conductor. In this case the anode and cathode are of the same pure metal. Both are carefully weighed before being placed in the bath. It is not essential that all of the current shall pass through the liquid. The bath may be placed in a shunt wire, and the quantity of metal carried over will be proportioned to the current. The amount of gain in the cathode will be the amount of loss in the anode. The density of the solution should remain the same, and the total weight of the two plates should remain unchanged. The shunted current bears a known relation to the total current, so that an example in simple multiplication will give the answer sought.

403. Electro-chemistry is utilized extensively in the coat-

ing of iron with zinc, the product being known as galvanized iron. The process consists in first cleaning the surface to be coated by immersing it in a bath of dilute acid, which removes all grease, dirt, etc., and then rinsing it in cold water. After being scoured with sand and again rinsed the articles are plunged into a bath of molten zinc, previously covered with a layer of sal-ammoniac, which forms a flux, and also prevents the oxidation of the melted metal. In the treatment of coarser articles the scouring is dispensed with. Nails, screws, chains, etc., are dipped in bundles, or in iron strainers, and afterward heated and shaken over a charcoal fire to separate them, as they cool.

404. Telegraph wire is galvanized by automatic machinery. The wire is drawn direct from the dies, through pipes kept at a white heat in a furnace, thence through a bath of hydrochloric acid, and finally through a tank of melted zinc. The heating and subsequent coating to an extent tempers the metal, rendering it more flexible than when it first leaves the dies. Iron for electric lines is largely being displaced by hard drawn copper, which, being lighter, occasions less strain on cross arms and poles, and permits of much longer spans, while offering less obstruction to storms.

405. Another method, applicable to large sheets of metal, consists in placing these, after pickling and scouring, in a bath between alternate layers of finely granulated zinc. The tank is then filled with a dilute solution of chloride of tin, and the galvanic action set up deposits a thin coating of tin upon the iron. The plates or other articles are then zinc coated as previously described. This process, while somewhat more complicated, produces a much superior quality of work for finer articles of merchandise.

# CHAPTER XVII.

## APPLIED ELECTRO-MAGNETISM.

406. In Chapter XIII we learned how magnetism may be developed by a current. The applications of this power for every day use are so extensive that a mere catalogue of these would occupy a volume.

407. Among the most general uses in which electro-magnetism is essential we find the electric telegraph.

408. Bishop Watson, in 1747, suspended 10,600 feet of wire near London, arranged on insulators, through which he obtained a discharge from a Leyden jar, and with which he endeavored to commuicate intelligence. In 1753 a detailed description of an alphabetical telegraph was published in the Scot's Magazine; in 1774 at Geneva, Switzerland, an experimenter named Le Sage constructed a telegraph of twenty-four insulated wires. To one end of each of these a pair of pith balls was suspended. When a static machine was brought into contact with the opposite end of one of these wires the balls diverged by repulsion, thus indicating a letter. Lomond followed, using a single wire with which the separate letters were designated by the number of repulsions. Sparks were used in a similar manner, but the inherent difficulties pertaining to static electricity rendered fruitless all endeavors in this direction.

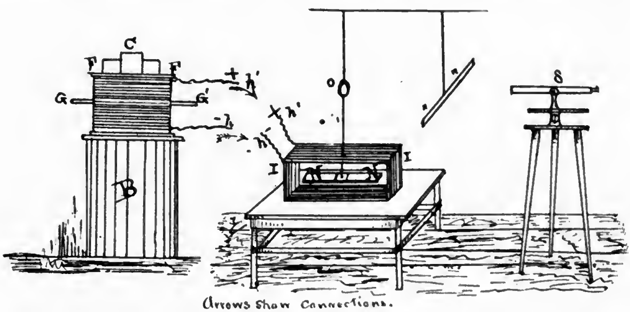
409. Volta's discovery of the battery in 1800 opened a new field for experimenters; Sömmering, in 1808 invented a system embracing 35 glass tubes closed at one end, each inverted over two gilded metallic strips, and thus connected to the wires leading to the transmitting station. Then by connecting the + pole of the battery to one wire and the −

to another, the circuit at the receiving end would be closed by the two receiving strips and the water. One of the terminals so connected would show bubbles of hydrogen, the other of oxygen. One of the strips was also connected with a zero wire, so that when only a single letter was transmitted the positive pole was connected to this wire and the negative to that necessary to indicate the required letter or numeral. When two letters were sent simultaneously the letter at the hydrogen terminal took precedence. The inventor proposed calling attention at the receiving station by liberating an alarm through pressure from the accumulating gas. Dr. J. Redmond Coxe, of Philadelphia, in 1810, proposed a system based on the electro-chemical deposition of metallic salts practically worked out by Alexander Bain, and patented in 1846. Sir Francis Roland previous to 1823, sent intelligible messages through more than eight miles of wire, insulated and suspended in the air. His elementary signals were the mutual repulsion of two pith balls, produced by a static discharge. Two lettered dials, one at either extremity of the line, revolved synchronously beneath a covering with a small opening showing but one letter at a time. As the required letter passed the opening the electrometer at the receiving end was actuated by the sender charging the wire. These dials never stopped, and any slight inaccuracy was corrected by moving the cover. For calling attention—his call—he used the discharge of a small gas pistol, by means of a spark. Ronald's telegraph contains the germ of Hughes' printer.

410. Prof. Hans Christian Oersted's discovery of electromagnetism was almost instantaneously followed by attempts to utilize this force for telegraphic purposes. Suspended needles within solenoid coils were shown by Ampére before the French Academy in 1820. Baron Schilling of Cronstadt, in 1832, exhibited a single needle system before Emperor Alexander, as an improvement on a five needle system of

his own conception. Gauss and Weber improved on Schilling's system by constructing an apparatus in which there was a single magnetic needle inclosed in a coil. Induction currents produced by a magneto-electric inductor deflected this needle.

411. Figs. 71 and 72 show the Gauss and Weber improvement. A hollow standard (B), incloses three permanent magnets (C), each weighing 25 pounds, placed with similar poles together and forming a huge compound magnet. Surrounding these, at their upper extremity, a coil of wire upon a wooden bobbin (F F), was fitted with handles (G G′)




**Figs. 71 and 72.**

GAUSS AND WEBER'S TELEGRAPH.

by which it could be raised from the base. This coil contained 7,000 feet of insulated wire. Now, as the movement of a coil so situated will develop a current in the two wires (h (h′), in one direction when raised, and a reverse current, when lowered again, if such connections are made as will complete the circuit, the current in a second electro-magnet properly arranged will be capable of deflecting a magnetic needle.

412. Fig. 72 represents the receiving instrument. The

two wires (h h′), lead from similar wires through the electro-magnet (I I), which incloses a permanent magnet, 1½ feet in length, suspended from the ceiling of the room. A portion of this suspension consists of a spindle. To this is attached a mirror (O), in which, when at rest, a graduated scale (n n) is reflected at zero. A telescope (S), directed at the mirror (O), will detect the slightest variation in the parallelism of O and n n, occasioned by a movement of N N and O. Here we have the fundamental base of the European systems of needle telegraphy, and of the first cable systems. The alphabet consisted of combinations of movements to the right and left, one of these being called dashes, and the other dots, quite similar to the Morse alphabet of today. There is quite a marked similarity between this system of telegraphy and the reflecting galvanometers described in Chapter XIII.

413. Prof. Steinhill of Munich, who first announced the discovery that the earth might be made to supersede the return wire, at the request of Gauss and Weber, applied himself to the perfection of their invention. His efforts resulted in developing a convenient telegraphic alphabet out of the two elements, dots and marks. Two needles were employed either of which was deflected according as a positive or negative impulse was sent, the deflections being always on the same side. Sometimes these signals were read by sight and sometimes the needles, made heavier, were made to strike two bells having different tones. These were not entirely discarded in Europe as late as 1878. Another arrangement of this prolific experimenter was the production on a strip of ribbon paper of a series of dots. Two capillary tubes charged with ink were made to touch the moving paper, thus in a series of dots leaving a permanent record. Telegraphy had now reached a possible rate of speed of something over six words per minute.

414. In 1832, while returning from Europe, Prof. Morse,

a portrait painter, conceived the idea of an electro-magnetic telegraph, which should consist of a suitable generator of current, a system of signs consisting of marks and spaces, to represent letters and numerals, a method of impressing these, either by pen or pencil, on paper, and a method of moving the paper tape at a uniform rate of speed.

415. The early experiments of Morse developed the fact that a current of low voltage was not capable of forcing its way through high resistances, and it became necessary to arrange some method by which to manipulate a line of over a few miles in length. This necessity developed the relay and the second or local circuit, and made possible the sending of messages over long lines.

416. Morse's first model, constructed in 1835, consisted of a bent rod of iron wound with a few yards of copper wire,

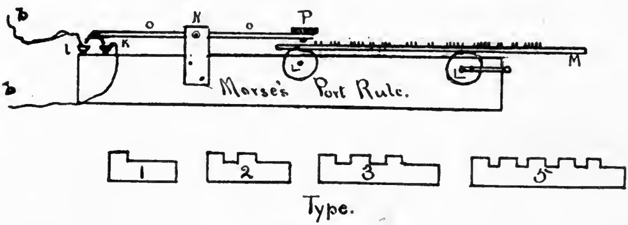



**Fig. 73.**

FIRST MORSE TELEGRAPH.

which had been insulated by wrappings of cotton thread, laid on by hand. The support for the receiving apparatus was fixed on a painter's easel frame, nailed to the edge of a table. A single cell of battery furnished the current for actuating the magnet, which, when charged, moved a lead pencil across a ribbon of paper passing beneath it. The works of a cheap clock moved the paper. The key consisted of a species of trough into which types could be set to form the

message. The types and port rule are shown in Fig. 73. When these were placed in the port rule they were drawn by the wheels (L L), under the lever (P o o); the raised portions of the type forced up the right end of the lever, depressing the left end, and forming connection with the two mercury cups (K 1), and the wires (b b), leading to the battery and magnet. The connection was broken by the weight (P), as soon as the raised portion of the type passed. The pencil, which rested constantly on the paper tape, was drawn at right angles to the movement of the tape, so that the marks were a series of zigzags, or V-shaped tracings, with a straight line connecting these; shorter between the parts of a letter, longer between letters and words. The points of the V or W-shaped marks were counted as dots.

417. The receiving magnet of the original Morse instrument was no less curious and crude than the port rule. The electro-magnet pulled the pencil at right angles to the motion of the paper, but both these awkward appliances were soon discarded. The electro-magnet was placed beneath the lever, at the opposite end of which three steel stylus points pressed the paper into three grooves in a brass cylinder, and the characters were embossed in the paper. Three grooves were thought necessary, to prevent possible error. A key, having a piece of wire bent in a V shape, for closing the circuit between the anvil and the key supplanted the port rule. The embossing lever had an arm reaching downward which rested on the fly wheel, to prevent motion when the line was not busy, and the third wheel had projecting pins, which, as the wheel revolved, moved a lever and struck a bell, four times for each revolution, to call the operator. There were but two offices on the first line, Baltimore and Washington. The presence of the receiving operator was not essential, as the two wires were independent, both being connected to the battery in Baltimore and

the ground plate at Washington; while one wire had its key at one station, and its register and relay at the other, and the second station had its apparatus reversed to this, so that Washington could write to Baltimore on one wire, but must receive on the other—in other words, there were two complete systems.

418. The principle of the electro-magnet is shown in Fig. 74, where M M represent the two legs of a horseshoe magnet, in which there is shown a soft iron core, C C, connected underneath to the soft iron bar, C′. An iron armature, A, held in its normal position by the spring, S, will, when current is applied, be drawn downward, overcoming the spring, and when this current is withdrawn, the spring will act and bring the armature back to its normal position. This is the action of the electro-magnet in the ordinary Morse system, reduced to its simplest terms. In practice it is necessary to restrict both the upward and downward stroke, by limiting stops.

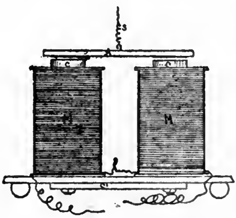


Fig. 74.

AN ELECTRO-MAGNET.

419. We have now reached the point where the first European and the first American systems arrived at the same results by two quite different methods. The first of these by variations of the galvanometer principle, in which the needle was the indicator, and the second, by the use of the armature.

420. Morse soon discovered that it was impossible for his lines to work perfectly, except over very limited distances, and the introduction of a second instrument, called the relay, was found to be necessary. The reason for this, as we have seen when studying current and potential, is read-

ily accounted for, when we remember Ohm's law, as there explained.

421. The relay, which is in fact a second key, will be understood by a glance at Fig. 75, which is intended to show the instruments and connections of an ordinary Morse line, consisting of three stations. The relays, R R R, are in series with the keys and batteries. An enlarged key, K, will show how these are manipulated to close and open the line, thus making and breaking the current, and actuating the relays, which in the diagram are all represented closed at C. The armature of each relay carries a second key,

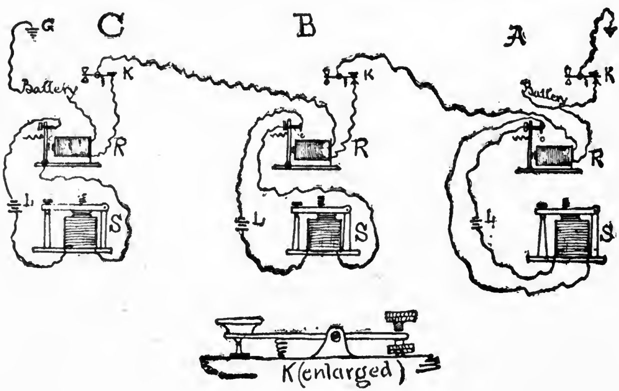



**Fig. 75.**

MORSE TELEGRAPH LINE.

which opens and closes the circuit through a battery, L, and the electro-magnet, S. This latter may be a register, carrying a paper strip or tape, or merely a sounder, for reading by listening to the sound made by the lever. This form of telegraph is what is known as the closed circuit sys-

tem, in which, when at rest, all the instruments are closed, and whatever is written goes the entire length of the line, from G to G, which are ground plates or earth connections, and serve the purpose of completing the circuit between the terminals.

422. The battery, on lines embracing more than two offices or stations, is divided, so that in case of a break in the line the entire service will not be disabled. If a break occurs, for instance, between A and B, B will make a ground connection on the A side of his office, and he can then work with C; while if the line between these two stations breaks, a ground connection on the C side of his station would enable A and B to work similarly.

423. The necessity for two circuits, called technically the main and local circuits, is fully explained by Ohm's law. In order to overcome the resistance of the line and instruments, it is necessary to employ a higher voltage, while for the short circuit of the local, which is all within the station, a less number of cells answers the purpose. The wire of the relay is much finer and the number of turns many more than those of the coarser wire on the local coils. A relay may measure as high as 400 or 500 ohms, while a local coil seldom measures over 14 or 20.

424. Registers are variously arranged to leave a record not only by embossing the paper, as we have seen, but by a species of fountain pen which traces an ink mark in some forms, and in others a stylus, made to press on and leave a transferred mark from carbonized paper.

425. The earlier Morse lines in Europe, like those in the United States, comprised but two stations, and the system of open circuit lines was generally adopted. Fig. 76 will show this form of telegraph. This single station is exactly duplicated at the farther end of the line. Each of the two stations has its battery. In a state of rest there is no cur-

rent on the line, but either station may call the other by depressing his key. The current from the calling station will pass through the backstop of the receiving station's key, through the receiver, and to earth. And of course the same would be true, reversed. If the operator at the station represented in Fig. 76 depressed his key, current from the battery there shown would flow through the distant receiver and close it. This receiver may be merely a local instrument or a relay like those in Fig. 75.

426. When the use of the telegraph became more general, means were required for intercommunication between several offices, and switches were introduced which cut off intermediate station grounds, and placed galvanometers in circuit at all stations. The movements of these indicated the fact that the line was being used. When the needle remained at zero for a specified length of time the line was known to be unoccupied, and was at the service of any operator. Calls were shown by the needle movements. Switches were used to throw current to the station at the right or left as required, and in some instances important intermediate stations were doubly equipped for working in two directions at the same time.

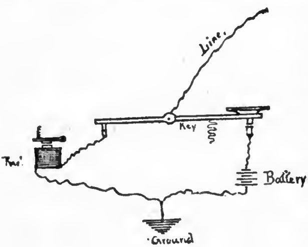


Fig. 76.

MORSE TELEGRAPH. OPEN CIRCUIT SYSTEM.

427. As the requirements of increasing business demanded enlarged facilities, lines increased in length, stations multiplied, and where in the earlier days stations were closed from supper until breakfast time, longer hours were

required, until all night service was inaugurated. Lines were duplicated, and inventors turned their attention to methods of making one wire do the work of two. Several methods of duplexing the wire were invented, all more or less successful. One of these, probably the earliest, is credited to Dr. Gintl, whose experiments were made between Prague and Vienna in 1853. Its principle was based on the fact that the direction of the winding of a helical coil determines the polarity of its core, as we learned in Chapter XIII. Now, if we wind two equal amounts of wire around an iron core, in such a manner as to send one-half the current around the core in the direction of moving clock hands, and the other half through the second wire in an opposite direction, no magnetism will be developed in the core—there will be no attraction or polarity. His plan required two batteries and a double key, which actuated them simultaneously, while a current from the other terminal of the line, passing through one half the relay coil, destroyed the equilibrium and produced a signal.

428. Among the several systems experimented and practiced with were many in which the above principle was a prominent factor. Batteries so arranged as to oppose each other at the home station, while an impulse from the opposite terminal would affect the home instrument; polarized relays—relays with permanent magnets for cores—and the use of chemically prepared paper, through which a current decomposed a salt and left a mark recording a signal from the distant terminal, while the current from the home battery was neutralized by an opposing current, and left no stain; these were the principal methods for arriving at the same result.

429. Still more complicated are the methods which followed for the simultaneous transmission of two messages in the same or opposite directions, and finally of quadruplex

and multiple transmission, until one wire has employed at the same time no less than 16 operators—eight senders and eight receivers—between New York and Philadelphia, in a successful experimental test of Gray's harmonic telegraph. These more complicated systems of telegraphy are beyond the scope of this work, and can barely be mentioned here.

430. A system of chemical telegraphy was introduced into the United States in 1849 and 1850 by Alexander Bain, of Edinburg, who utilized a current of electricity for decomposing a chemical salt, and forming a new compound on the paper wherever the current passed through it.

431. Paper saturated with a solution of prussiate of potash, sulphuric or nitric acid and water, was carried beneath a small iron wire resting upon it. When a current of electricity was sent through this wire to the earth, the electro-chemical action dissolved the iron, the potash combining with the metal and forming prussian blue. Each office had its own battery, and a pile of sheets of paper cut in the form of discs lay upon a revolving disc of iron, which communicated direct to earth. When receiving, the horizontal plate was set in motion and run by clockwork, the pen wire resting on the paper. This pen was held in a horizontal arm, from which a short piece projected carrying a pin which rested in a flat, helical groove or worm track. As the disc revolved the writing appeared in the same helical form, each revolution carrying the writing farther away from the center, until the sheet was filled, when it was removed and a fresh one took its place. The batteries used were of copper and zinc, in sand, saturated with sulphuric acid and water, the whole contained in wooden troughs 15 to 30 inches long by 5½ to 6 inches wide, with either slate partitions or glass vessels made to fit.

432. Bain's original idea was an automatic machine, in which a strip of paper, punched at leisure on shipboard,

could be put into a piece of machinery in which contacts would be made by the pressure of metal springs through the punched openings in the paper to a metal roller, both the springs and the roller being in the circuit when together, the circuit being interrupted by the paper. The message was thus to be ready for rapid transmission as soon as the steamship should arrive from abroad.

433. An unlooked-for trouble was manifest at the outset. After the first or second impulse the line, if a fairly long one, became charged with the positive current and failed to clear itself in time for the next signal. As a result the signals were not clear cut and distinct, the gradual leaking out of the current in some cases forming an almost perfect connection between the parts of letters, and sometimes between words, so as to render the reading, especially on long lines where he hoped for the most brilliant results, almost impossible. On moderately long lines the Bain system, manipulated by hand, on Morse circuits, was successfully operated in New England, New York and Canada.

434. The first Atlantic cable afterward showed the same trouble. Being the longest line then known it was deemed necessary to supply battery power proportioned to the distance. After a few impulses had been sent to line, the line, acting in the capacity of an overloaded Leyden jar or condenser, unable to withstand the strain of the static charge, burst, and became useless because grounded in the ocean.

435. The earlier European systems were based originally on movements of a galvanometer needle. Messrs. Cooke and Wheatstone were to English systems what Morse was to the American. The two inventors, who had experimented separately, became partners, and gradually improved upon the original inventions until only a single needle was required for their work. This single needle system was for many years the system in use on the lines of Great Britain,

India, and limitedly in France. The general principle will be understood by an examination of Fig. 77, which represents the outer case and signaling portion of a single needle instrument, inside of which is a coil surrounding a vertical needle. The pointer P is attached to the same shaft as the needle, and moves with it. Two stops, S S, limit the movement of the pointer on its right and left. This is the receiving instrument. The sending key is shown at A, which is double and should properly be called two keys, K K′, acting independently of each other. A battery is connected to two plates + and –, and the keys K and K′ are held by springs against the + plate, K′ being in contact with the earth at G. In this position a current from the distant station, after passing through the coil under P would come to the key via L, K, +, K′, and to G, the home battery being open.

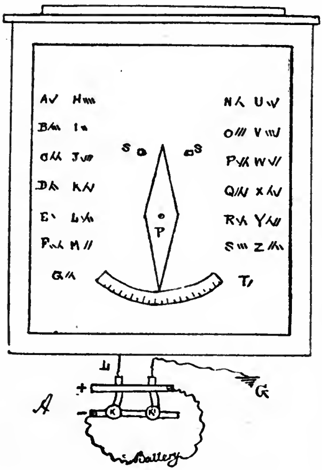



**Fig. 77.**

SIGNALING PORTION OF SINGLE NEEDLE INSTRUMENTS.

436. In sending a current to line depressing K will send a – current, while depressing K′ will send a + current. These reversals are made use of to designate the letters. For instance, suppose that depressing K deflects the upper end of P to the left. This is understood to be a dot. Now the key is permitted to resume its normal condition, and the pointer comes to zero again. Now depress K′ and a

deflection to the right results, which represents a mark, and a dot followed by a mark is the letter a. The letters are separated by uniform short spaces, the words by longer spaces. In Fig. 77 the letters on the dial are shown by the side of the telegraph signals, the dots being represented by short marks slanted upward to the left, the marks by characters slanting to the right.

437. In a somewhat similar manner in a system where two small bells are alternately struck, the left bell serves to indicate the dots and the right bell the marks.

438. The alphabet above referred to is that used in Europe quite generally, and differs somewhat from the American Morse. In the former there are no spaced letters, while in the latter there are several.

MORSE ALPHABETS.

| | American. | International. |
|---|---|---|
| A................ | · — | · — |
| B................ | — · · · | — · · · |
| C................ | · ·  · | — · — · |
| D................ | — · · | — · · |
| E................ | · | · |
| F................ | · — · | · · — · |
| G................ | — — · | — — · |
| H................ | · · · · | · · · · |
| I................ | · · | · · |
| J................ | — · — · | · — — — |
| K................ | — · — | — · — |
| L................ | —— | · — · · |
| M................ | — — | — — |
| N................ | — · | — · |
| O................ | ·  · | — — — |
| P................ | · · · · · | · — — · |
| Q................ | · · — · | — — · — |
| R................ | ·  · · | · — · |

| | | |
|---|---|---|
| S | ... | ... |
| T | — | — |
| U | ..— | ..— |
| V | ...— | ...— |
| W | .—— | .—— |
| X | .—.. | —..— |
| Y | .. .. | —.—— |
| Z | ... . | ——.. |
| & | . ... | None |
| 1 | .——. | .———— |
| 2 | ..—.. | ..——— |
| 3 | ...—. | ...—— |
| 4 | ....— | ....— |
| 5 | ——— | ..... |
| 6 | ...... | —.... |
| 7 | ——.. | ——... |
| 8 | —.... | ———.. |
| 9 | —..— | ————. |
| 0 | ——— | ————— |
| Period | ..——.. | ...... |
| Comma | .—.— | .—.—.— |
| Interrogation | —..—. | ..——.. |
| Exclamation | ———. | ——..—— |

International.

| | |
|---|---|
| Ch | ———— |
| ä | .—.— |
| ö | ———. |
| ü | ..—— |
| é | ..—.. |
| Parenthesis | —.——.— |
| Don't understand | ..——....——.. |
| Erase | ... ... ... |
| Finis | .—.—.—. |
| Apostrophe | .————. |

| | |
|---|---|
| Hyphen ........................ | — · · · · — |
| Paragraph ...................... | · — · — · · |
| Quotation ....................... | · — · · — · |
| Understand......................... | · · · — · |
| Wait ................. .......... | · — · · · |
| Call......................... | — · — · — · — |
| Cleared out O. K........... | · — · · — · · — · |

439. An automatic system, an adaptation of the principle governing Bain's chemical system, is the invention of Wheatstone. In this system a ribbon of paper is previously punched with a series of uniform holes through the entire length of the strip, which are merely to engage in the teeth of a rack wheel, for carrying the strip uniformly forward. Either side of this row, the holes which go to make up the characters at the receiving station are punched. When this paper is ready the end of the strip is placed between two rollers, through which the tape is drawn, contact being made through the perforations. The Wheatstone improvement over Bain's system lies mostly in the fact that the currents are alternate, the negative and positive currents neutralizing each other as soon as an impulse is completed, thus cutting off the tailing or drag, caused by the gradual leaking out of the current which remains after the signal. The signal in fact consists of two impulses. For instance, a dot will be produced by an instantaneous current immediately followed by an impulse of an opposite character; and a mark will be produced by a current followed at a longer interval by an opposite one. Fig. 78 represents the strip of

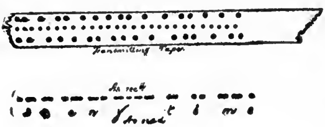


Fig. 78.

WHEATSTONE AUTOMATIC TELEGRAPH.

paper as punched, and also the strip at the receiving station, the sentence reading "at any time."

440. The advantages of automatic telegraphy are perfect signals at a high rate of transmission, and the capability of repeated use. Thus in the British postoffice telegraph system, a dispatch originating in London may be transmitted direct to Liverpool, Glasgow, Dublin and other places virtually at the same time. The tape having run a few feet through the first instrument is put into the second, third and fourth consecutively, and as the instruments run at the same rate of speed, the last line has nearly finished when the first is through. Fewer operators can accomplish much more work. The Wheatstone system has come into use in the United States within a comparatively few years, and bids fair to remain a fixture on Morse lines.

441. Another method of transmitting intelligence in several directions at the same time is by means of repeating instruments, which are automatic in their action, doing the work of an operator at points in the middle of long lines, and at places where lines diverge from the through system. These—and there are several of them—are too complicated for an elementary work, but this much may be said of the principle of them all: that they embody the idea of a second circuit and battery actuated by a first circuit key, as we have seen in the relay and sounder, shown in Fig. 75. This action is readily understood to be capable of transmitting in one direction, and by means of an additional set of relays and a ground connection at the repeating station the reverse action is made possible, so that the opening of a key anywhere on the lines opens all the circuits then in service.

442. A novel and ingenious self-adjusting relay and sounder combination is shown in Fig. 79. A peculiarity of this combination is that there are no springs, and the armature of the local circuit is not opened or closed by the relay through contact points, as in the Morse systems. There are

two local batteries. The regular local circuit normally passes through the coils D D and C C of the sounder, the latter being the stronger magnetically of the two, so that

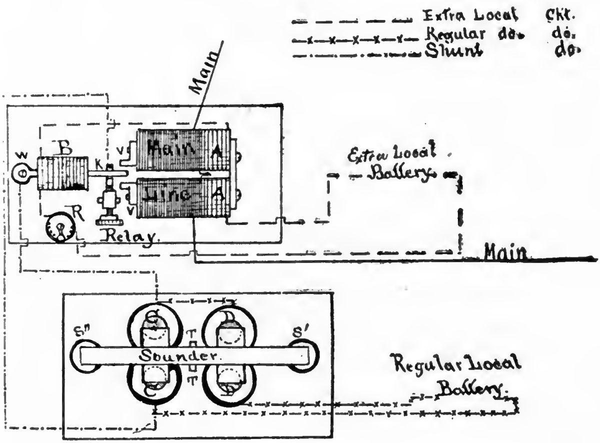



**Fig. 79.**

C. H. HASKINS' SELF-ADJUSTING RELAY AND SOUNDER.

the sounder armature, which moves like a teeter on the axle T T, is normally held down at the S″ stop. This circuit has a shunt line which, when closed at K, cuts out C C, allowing D D to pull down the lever on the S′ stop.

443. The extra local battery circuit runs through the coils A A thence through B, the regulating rheostat R and back to battery. This current polarizes the cores of the relay, the pole pieces V V, magnet B and the armature which moves on a center W, making or breaking the shunt circuit before mentioned at K. The main line circuit is wound on the same core as coils A A. The action of the combination is

as follows: When a sending key is closed the main current being opposite to and stronger than the current in A A overcomes its polarity and attracts the polarized armature toward K, closing the shunt, cutting out C C, and allowing D D to pull the opposite end of the sounder down upon the stop S′. Opening the key reverses the action, allows A A to control the main magnet, and the magnet B breaks the contact at K, opens the shunt around C C, and the sounder lever again comes down on S″. This instrument was used on the North Western telegraph lines for several years, and gave perfect satisfaction in every particular. The novel combination was the invention of Mr. C. H. Haskins, then Gen. Supt. of the N. W. Telegraph Co.

444. Multiple telegraphy has been accomplished by several methods, one of which, Meyers', made one wire do the work of several, by synchronous clockwork movement, a rotating wheel at each extremity of the line having a click for each revolution of the wheel. At the moment of this click the two stations were in connection, and all other stations were open, so that a letter could be made by either. For the space of one instant of time that line was theirs alone. The revolving disk which thus divides the time and contacts has 48 divisions, twelve to each quarter of the circumference. Eight of these are grouped in pairs, while four are connected directly to earth. The transmitter has eight keys, like piano keys, four black ones which represent the dots, and four white ones representing the marks. Depressing these by the necessary combination produces at the distant receiver magnets the desired combinations of dots and marks to represent the letters.

445. Other systems depending on synchronous movements of the apparatus are the various printing telegraphs, principal among which may be mentioned that of Hughes, extensively used in Europe, and which has been successfully

duplexed. The list of these instruments is by no means inconsiderable, and includes market report tickers, etc., synchronism being accomplished through the vibrations of adjustable springs, pendulums, or the like.

446. Fac-simile telegraphs have been attempted but without commercial success. The earlier of these accomplished the result by having the message written with an ink which is a conductor, the receiving paper like that in the Bain system, capable of discoloration by electric current. The cylinder around which the written message is placed is carried slowly longitudinally by a worm gear, an iron point resting constantly on the revolving copy. The circuit is closed wherever the inked portion comes beneath the pen, through the cylinder, which is grounded. The current thus sent to line passes through the distant paper, leaving a record on its way to earth through the receiver's cylinder.

447. Probably the most perfect of this class of telegraphic inventions is the telautograph of Prof. Elisha Gray, of Chicago, by means of which an ordinary message is written at the distant station simultaneously and correctly.

448. As we have seen, the laws governing vibrations of all kinds are essential to synchronous motion. Prof. Gray has availed himself of this principle in his multiple system of telegraphy. By dividing a large battery into sections, each of which can be thrown into an individual rate of vibration by the aid of a tuning fork contact, an instrument at the distant end of the line will respond to that rate of vibration, and no other, while a second key and tuning fork having a different rate will be responded to by a second receiver. Several of these may be closed and send out their vibratory currents at once, yet each receiver will select its proper tone, and vibrate correspondingly. Thus the tuning fork sending a portion of the current having a rate corresponding to the tone C, will actuate the C fork at the distant end. So A will

call for A, G for G, etc. In this way several messages may be sent simultaneously in opposite directions. (429.)

449. Vibratory law is also the basis of telephonic communication. The telephone transmitter is made up of a thin iron diaphragm which is held close to a button of carbon. Carbon has this peculiarity—the more it is compressed the better conductor it becomes. Between the carbon and the diaphragm is a platinum contact, touching—very lightly—both.

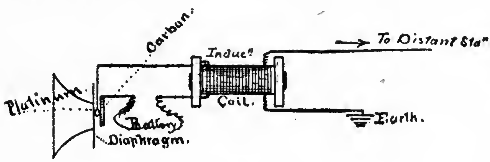



Fig. 80.

TELEPHONE TRANSMITTER.

Connected in circuit with the platinum and the carbon is a battery and the primary of an induction coil. The secondary of the coil goes to earth in one direction, and to the distant station in the other. The original telephone invention had no separate transmitter, the object of which is to intensify the vibratory action, and render the apparatus more efficient. The action of the transmitter will be better understood by an examination of Fig. 80. The vibrations of the diaphragm acting upon the carbon, vary its resistance, and consequently the amount of current flowing into the primary of the coil. These changes are intensified in the secondary, and render the telephone more efficient than the orginal Bell instrument. In the receiving instrument electrical vibrations become magnetic vibrations, the diaphragm of the receiver responds, the air takes them up, and the vibrations, which are now recognized as sound by the tympanum or ear drum, exactly repeat the original sound of the transmitter.

450. No two voices sound exactly similar. This is because of the over tones, which go to make up the timbre or quality

of all sounds. A flute, a violin and a clarionet may all sound the same note but the tones are not similar. It is this difference in the make-up of the human voice which renders it difficult or easy to be understood by telephone. The higher the tone the finer the vibrations, and the less distinct; while a lower pitch of voice will send out coarser vibrations and accomplish better results.

451. The minor applications of electro-magnetism for various purposes, are almost innumerable, as bells, burglar alarms, gas lighting, door openers, etc. In the majority

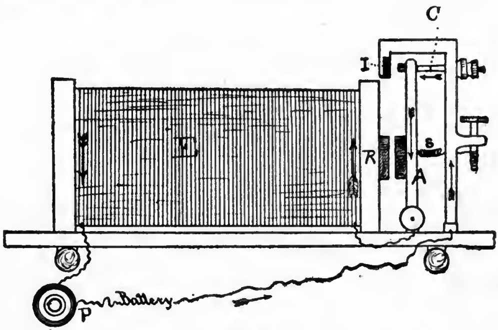



Fig. 81.

PRINCIPLE OF THE VIBRATING BELL.

of these applications an automatic circuit breaker is made use of to make a vibratory ring. The constantly closed key, but for the circuit breaker would simply hold the circuit closed after a single stroke of the bell. Fig. 81 will show the method of accomplishing this breaking of the circuit into rapid blows automatically. The combination includes the electro-magnet E, armature A, contact points C, adjusting spring S, push button P, battery and wires. In a normal position the spring S holds the contact closed at C. Now, if we close the circuit by pushing on the button P, E becomes

magnetic. A is drawn to the core R, and the circuit is broken at C. In the standard at I a piece of hard rubber insulator is placed, otherwise the contact there formed would hold the circuit closed and there would be no vibration. The current direction is shown by the arrows.

452. In order to convert this "buzzer" into a vibrating bell, it is only necessary to so arrange the parts that the armature lever A shall strike a bell at I, or, if desired, be made to vibrate between two bells, striking each alternately, with the forward and backward stroke

453. Electric gas lighting circuits include a spark coil which intensifies the result when the circuit is first closed and then broken by the wiping contact at the burner, when the pendant is pulled down. The little hook across which the spring wire rubs is in the line to battery, through the spark coil, and is insulated from the gas fixture. The distant terminal of the battery is either grounded or brought back to each chandelier on a metallic return wire. The circuit is normally open. When the pendant is pulled down the contact is made at the same instant the gas is turned on by a ratchet controlled by the pendant. As the spring wire leaves the hook, the induction spark ignites the gas. The induction or spark coil has no core, the self induction of the various turns of wire being sufficient for the purpose.

454. The push button or automatic lighter has two contacts, one for lighting and one for extinguishing the light. These are connected to two electro-magnets at the burner. The armature is double, and moves on a center below these electro-magnets. A variety of circuit breaker is so actuated by the armature as to break circuit and spark at the slit in the burner. The first movement of the armature moves the valve, opens or closes it according to which contact is pushed. The buttons are differently colored, usually white for lighting, black for extinguishing. A bell or buzzer in a local or secondary circuit notifies when the line is short circuited at a lamp or elswhere.

455. In burglar alarm circuits the two wires are carried to

each opening to be protected. One of these wires starting from the battery is brought to a closing device which is normally open. The other leads from the battery, through an annunciator coil, and to the other half of the closing device, passing through the alarm bell. When the contact is made at the closing device, by opening the protected door or window, the annunciator drops, showing the locality of the opening, and the bell rings. There are several varieties of attachments—one for testing each circuit without ringing the bell, another for a continuous ringing of the bell, even though the opening be closed instantly, until switched off, another for automatic lighting of either gas or electric lights in case of an alarm, and others. A variety of burglar alarm is made in the form of a mat which is lain inside of a door, or beneath a window to be protected. This mat is made with a multiplicity of connections to both sides of the circuit so arranged that stepping upon the mat closes the circuit, and rings the bell, drops the annunciator, etc.

456. In connection with an alarm bell the hands of the clock may be made to close the circuit at any wished for hour. Circuits leading to a central station receive by electro-magnetism the reports of the night watchmen who are required to patrol a building, turning in an alarm at regular hours, failing of which a messenger is sent to learn the cause of failure to report.

457. In fire department service the street box mechanism performs the part of an automatic key, the spring actuating it being wound by the act of pulling down a lever. At many engine houses or stations of other fire apparatus at night the first opening of a circuit releases the armature of an electro-magnet, allowing a weight to drop, which, by means of a rope attachment pulls the clothes off all the beds. The horses are released from their stalls by similar appliances, while the register is recording and the gong is ringing the number of the box.

# CHAPTER XVIII.

## FORCE. WORK. ENERGY.

458. We may define force as any cause which produces or tends to produce a change in the state of rest or of motion of any body. "The true measure of a force which produces motion is proportional to the pressure, and consequently momentum is the true dynamical measure of force."

459. To accomplish any effect, or to do work, a force must produce motion. A weight upon a table, unless the table gives to the pressure, that is unless the weight moves, will accomplish nothing; and the weights of a clock, when the machinery is not running, produce no results.

460. If, however, the clock is moving, then there is a conversion of energy from that which resides in the weight to that which produces motion, and overcoming all obstructions, friction, atmospheric resistance, etc., moves the machinery of the clock; conversion from potential energy which is stored, to kinetic or active energy. We have alternate examples of the two energies in the action of the striking weight—now still, now moving, and expending a portion of its energy in setting the surrounding air in vibrations which we recognize as bell tones. Examples of this stored energy are found in coiled springs, the strained bow, the pent-up water in a high tank, etc.

461. The energy stored in any body in motion is an exact measure of the work necessary to bring that body to rest; and the same amount of force properly expended will set it in motion at the same rate of speed as before.

462. We may calculate the amount of work which a given head of water will furnish in driving a turbine with ma-

chinery attached, but there is always a loss (so called) due to friction, etc. While this loss of useful power exists, there is no loss of energy. There is exactly as much energy in creation as there ever has been, but it may change its nature.

463. When mechanical power is lost through causes just mentioned, it is changed to a new form of energy—changed into heat. The lack of lubrication in the journal of a shaft uses up the mechanical power and converts it into heat through friction, which thus demands extra work. The muscular energy applied by the savage who creates a fire by rubbing two pieces of wood together is an example of similar conversion.

464. In the earlier days of creation huge, rank masses of vegetation absorbed the heat of the sun, grew to magnificent proportions, fell, decayed, and eventually were changed by chemical forces into coal. The energy of that light and heat and moisture are imprisoned in the coal today, and we have only to set fire to it to release the heat and light dormant from the earth's earliest infancy.

465. Assuming that there should be a fixed relation between units of heat and those of gravitation, James P. Joule, F. R. S., LL. D., one of the most ingenious of experimental philosophers, devised an apparatus for determining that relation. A paddle wheel was made to revolve in a closed vessel, filled with water, the wheel being moved by the fall of a known weight through a measured space. The friction of the water particles obstructed the paddles, and the wheel became quiet almost the instant the weight ceased to act. The quantity of water and the rise in temperature due to the conversion of the mechanical into thermal energy, formed the basis of a calculation which showed that heating one pound of water one degree Fahrenheit is equivalent to 772 foot pounds; or, if a pound of water fall to the ground through 772 feet, and be then suddenly stopped,

its temperature would then be raised one degree. And again, the heat that would raise the temperature of one pound of water one degree, is capable, if properly applied, of raising 722 pounds one foot high. This number is known as the British heat unit, or Joule's equivalent. It differs from the international Joule adopted by the congress of 1893, which is given as equal to $10^7$ units of work in the C. G. S. system, or practically by that energy continued for one second by one international ampere in one international ohm.

466. Thomson has figured the energy of a cubic meter of sunlight at the earth's surface as somewhere near 12,000 foot pounds—the equivalent of 10,000 horse power—in each square foot of the sun's surface. This is made up of those vibrations we know as heat and light, which are so near akin to electricity and magnetism.

467. The potential energy of gravitation may be transformed into light and heat. With this we may drive a water wheel to turn a shaft carrying an emery wheel, and applying an ax or knife to the wheel, sparks show the absorption of heat by the particles torn off through the abrading friction; or we may turn a plate electric machine or a dynamo, and the developed static or dynamic charge may be made to develop light, heat and motion again, or produce chemical decomposition.

468. Chemical action in a voltaic combination will develop any of these phenomena when properly manipulated.

469. In all these results we see the transmutability of the various forces, and can more readily understand the undeniable fact that no energy is ever lost in reality, although its form may render it unavailable for our purpose.

470. Faraday, following a hint from Joule, transformed the induction of the earth's magnetism into electric current by rapidly revolving a metal disk, one terminal wire being connected at the axis and the other touching the periphery

of the disk. Here we have an energy developed from muscular exertion, a result which is increased in proportion to the muscular effort. This animal energy is simply a transformation of the potential residing in the food consumed. The heat of the body is another transformation of the same potential.

471. Work is the successful overcoming of resistance. We may endeavor to push down a wall, and, while the expenditure of energy may create fatigue, if we do not accomplish the end sought we have done no other work. If we lift a stone from the ground we accomplish work, and the higher we raise it the greater the amount of work accomplished. A man weighing 150 pounds ascending a flight of stairs comprising twenty steps of six inches each lifts 150 pounds ten feet; but the energy is gradually expended through a complicated system of levers—the muscles and bones; and what is practical by this modification of an inclined plane would not be possible under most other circumstances.

472. The amount of work which can be done—for instance in the case just mentioned—depends on the time rate of doing it. By taking time enough the man could walk to the top of the highest monument with but little fatigue, while to run up a flight of twenty steps would be exhaustive.

473. Work is accomplished by an electric current in producing chemical, thermal, magnetic and luminous results.

474. The power to accomplish electrical work is called electrical energy. The amount of current flowing, multiplied by the pressure or potential of that current is the amount of work accomplished.

475. Electric energy is generally figured in electrical horse power; or, in other words, the rate of doing work. In [illegible] we have seen that the rate of doing work may seriously affect the result. A flow in amperes per second multiplied

by the volts will give a product of volt-amperes or Watts. The Watt is 1-746 of a horse power, which is 550 foot pounds per second. In formula this may be written $C E = W$. Hence to obtain the rate of horse power of any electrical appliance, multiply the volts by the amperes and divide by 746. The formula may also be written $C^2 R = W$, and $\frac{E^2}{R} = W$.

476. To prove these different propositions, let us suppose we have an electrical source of 40 volts flowing through a resistance of 8 ohms, which will give us by Ohm's law a current flow of 5 amperes. Then:

(*a*) $C \times E = 40 \times 5 = 200$ Watts.

(*b*) $C^2 \times R = 25 \times 8 = 200$ Watts.

(*c*) $E^2 \div R = 1600 \div 8 = 200$ Watts.

477. The erg is the unit of work done when a body is moved through one centimeter of distance with a force of one dyne, and is equal to one dyne centimeter. Hence if one gramme is raised vertically one centimeter the work done is equal to 981 ergs, because it requires 981 dynes to balance one gramme.

478. The disadvantage of writing these and similar large numbers in full must be apparent to all, and a method of abbreviation has been quite generally adopted, which is at once simple and perfect. Thus, if we desire to write 63,000,000,000, it is shortened into $63 \times 10^9$, or 63 followed by nine ciphers; while if the amount is less than a whole number the fraction is indicated by the minus mark before the exponent. Thus $4 \times 10^{-6}$ would represent the decimal .0000004.

479. The inconvenient dimensions of the fundamental units of the C. G. S. system have led to the adoption of what are known as the "practical units," which are larger or smaller than the fundamental units. For example the volt is $10^9$ absolute units, but the ampere is only one-tenth the absolute unit, and the coulomb is one-tenth the absolute

unit of quantity, while the farad is $10^{-9}$ the unit of capacity, etc.

480. The derived units related to the fundamental units, Length (L), Mass (M), Time (T), are various. For instance the unit of area ($L^2$) is the square centimeter; the unit of Volume ($L^3$) is the centimeter cubed; the unit of Velocity (V) is unit distance moved in unit time. There are units based on the repulsions or attractions between unit magnet poles at unit distance asunder, and units of heat measurement. A few of the units of Work, Power and Force are given in a tabulated form, from some long tables in Carl Hering's "Equivalents of Units of Measurement," revised expressly for this work by their author, and published by his permission. They are given to illustrate the Units System:

## TABLE I.

### WORK.

| Units in Order of Size. | Equivalents. | Approximate Values Within a Few Per Ct. |
|---|---|---|
| 1 erg | = 1. dyne-centimeter | 1 |
| 1 erg | = .0000001 joule | |
| 1 gram-centimeter | = 981. ergs | 1000 |
| 1 gram-centimeter | = .00001 kilogram-meter | |
| 1 foot-grain | = 1937.5 ergs | |
| 1 joule or 1 volt-coulomb, or 1 watt per sec. or 1 volt-ampere per second | = 10000000 ergs | |
| " " | = .737324 foot-pound | 3/4 |
| " " | = .101937 kilogram-meter | 1/10 |
| " " | = .0013406 horse-power p'r sec. | 4/3000 |
| " " | = .0009551 pound-Far. heat unit | 2/2100 |
| " " | = .0002778 watt-hour | 3/11,000 |
| **1 foot-pound** | = 13562600 ergs | |
| " | = 1.35626 joules | 4/3 |
| " | = .00181818 horse-p'w'r p'r sec. | 2/1100 |
| " | = .0003767 watt-hour | 3/8000 |
| **1 watt-hour** | = 3600 joules | |
| " | = .0013406 horse-power hour | 4/3000 |

| | | |
|---|---|---|
| 1 horse-p'w'r hour | = 2685400 joules | |
| " " | = 1980000 foot-pounds | |
| " " | = 745.941 watt-hours | |

## TABLE II.

### POWER.

| | | |
|---|---|---|
| 1 erg per second | = .0000001 watt | |
| 1 watt, or 1 volt-ampere, or 1 joule per sec. or 1 volt-coulomb per second | = 10000000 ergs per second | |
| | = 44.2394 ft.-pounds per minute | 90/2 |
| | = 6.11622 klgr.-meters per min. | 6 |
| | = .0013592 metric-horse-power | 4/3000 |
| " " | = .0013406 horse-power | 4/3000 |
| 1 horse-power | = $745.94 \times 10^7$ ergs per second | |
| " " | = 745.941 watts | 3000/4 |
| " " | = 33000 ft.-pounds per min. | 100000/3 |
| " " | = .74594 kilowatts | 3/4 |
| 1 kilowatt | = 1000 watts | 1000 |
| " | = 1.3406 horse-powers | 4/3 |

## TABLE III.

### FORCES.

| | | |
|---|---|---|
| 1 dyne | = 1.0194 milligrams | 1 |
| " | = .015731 grain | 4/250 |
| " | = .0010194 gram | 1/1000 |
| " | = .00003596 ounce avoirdupois | |
| 1 milligram | = .981 dyne | 1 |
| 1 grain | = 63.568 dynes | 500/8 |
| 1 gram | = 981. dynes | 1000 |
| 1 oz. avoirdupois | = 27811 dynes | |

## TABLE IV.

### ABSOLUTE ELECTRICAL UNITS.

| | | |
|---|---|---|
| 1 Coulomb | = $10^{-1}$ | electro-magnetic units of quantity |
| 1 Ampere | = $10^{-1}$ | " " " current |
| 1 Volt | = $10^{8}$ | " " " E. M. F. |
| 1 Ohm | = $10^{9}$ | " " " resistance |
| 1 Farad | = $10^{-9}$ | " " " capacity |
| 1 Joule | = $10^{7}$ | absolute units (ergs) of work |
| 1 Watt | = $10^{7}$ | abs. units (ergs per sec.) of power |

# CHAPTER XIX.

## LIGHT AND POWER.

481. We have seen in studying the action of telephones, how a moving diaphragm is capable of setting up a vibratory action in a magnetic field. This action is the fundamental principle of electric lighting and electric power. We have learned that when a conductor is moved across the lines of magnetic force there is an electro-motive force developed in that conductor. This force is at right angles to the line of motion, at right angles to the direction of the lines of force, and to the right of these when viewed from the place whence the motion proceeds.

482. But it is necessary that the moving conductor should so intercept the lines of the magnetic field as to constantly change the number of these while passing, in order to develop a difference of electric potential, or electro-motive force, a result which is due to a conversion of the mechanical energy into electrical energy through the medium of magnetic induction.

483. If in these movements the conductor enters the lines of force of a magnet—whether permanent or not—passes directly across the field and emerges from the opposite side, the potential difference will increase as the lines increase in number—in density—until the center of the field is reached—then decrease as the lines of force become less, and become extinct as it passes from the field. Thus the approaching and the receding movements produce currents of opposite polarity—alternating currents. The e. m. f. developed by such action is dependent on several factors—the rate of motion, the intensity of the field, the angle at which the

lines are cut, the length (as in a coil) of the conductor so cutting the field. Increase in any of the factors mentioned will increase the e. m. f., while a decreased e. m. f. will follow the diminishing of either.

484. The developing of one volt of potential difference requires that the wire shall cut through 100,000,000 lines of force per second. Doubling the other factors, or in any way cutting more lines per second, will increase the output in proportion.

485. If now we so arrange our coil of wire upon an axle revolving between the two poles of a permanent or an electro-magnet at right angles to the lines of force, it is evident we will develop a current which will be alternately direct and reverse at each revolution—for it has been shown that the induced current is in one direction as the coil approaches the center of the field, and reversed as it leaves the field in crossing through it. So also is the effect of passing from one field—the north, for instance—to the south field; and if the coils of our moving wire are wound one half right and the other half left, we will have no result; for the induction effect will be equal and opposite.

486. It is evident that a revolving shaft having but a single coil would accomplish but little as a current generator, and an arrangement by which several such coils, or different portions of the same coil, can be successively carried through the magnetic fields was necessary.

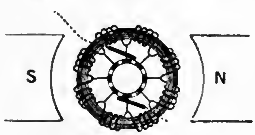



Fig. 82.

CLOSED COIL RING ARMATURE.

487. This revolving portion, called the armature, arranged to accomplish the desired result is shown in Fig. 82, named for its inventor, a French electrician, a Gramme ring. The wire is continuous, or closed on itself, but there are eight attached branches leading down to the center of the revolving arma-

ture, where these are connected to eight contact plates or bars, insulated from each other. This combination of plates and insulating material is called a commutator, and revolves with the armature, being fixed on the same shaft. Resting on this commutator, at opposite extremes of the diameter, are two metal or carbon fingers or brushes, which take off the current, the one only receiving the positive while the other carries away the negative impulses. These brushes are adjustable around the commutator, and when moved to the position of greatest efficiency are fixed in place, from whence during uniform motion of the machine and constant line resistance, they require but little changing.

488. The winding here is that of the original Gramme ring, but experience showed that the continuous ring could be improved upon by cutting it up into separate coils, the two ends of which are carried to the commutator bars, and thus, while the same virtual result is arrived at, the danger of current jumping from point to point in the coils is greatly reduced.

489. The coil of soft iron—the core—of the armature shown was subsequently modified and made up of disks of thin, soft iron, insulated from each other to avoid the setting up of wasteful heat energy in the core itself, which would reduce the efficiency of the machine, as will presently be explained.

490. A modification of the ring armature is known as a drum armature. If we imagine the same amount of wire wound on a long, thin shaft instead of a ring, we will have the drum or Siemens armature. In effect the two are alike, but the forms are something different. (Fig. 83).

491. A third form is known as the pole armature, and has a core like the spokes of a wagon wheel, round which a continuous wire is carried to each in succession, and con-

necting wires taken to the commutator sections as before described. (Fig. 84).

492. A fourth form of armature is called the disk armature, from its disk-like or flattened shape.

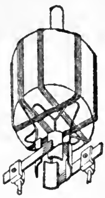


Fig. 83.

CLOSED COIL DRUM ARMATURE.

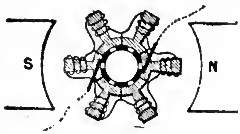



Fig. 84.

CLOSED COIL POLE ARMATURE.

493. While in general these various forms arrive at the same result, there are objections which have virtually driven the last two from the commercial field.

494. The evenness of the electrical flow is of course dependent on the number of sections of the armature windings, each of which has a corresponding section or bar in the commutator, and these may number over a hundred in a commercial machine.

495. All the armatures so far mentioned are of the closed coil type, the general arrangement of wire being typically that shown in Fig. 82. In these the sections are so connected that they may be considered much the same as a battery of cells in series. The different coils at any instant of the revolution are all connected at opposite points of the armature circumference, and in opposite magnetic fields—at the points of greatest magnetic density—are simultaneously connected to the two brushes which close the circuit and permit the current flow. Tracing the circuit from the point of contact with one brush, we see that its course is through lines of force becoming gradually less and less dense, until it reaches a point of neutrality, followed at once by an increasing density of opposite polarity.

496. Now each of these coils contributes its mite to the general fund, so that when it gets to the brushes the cur-

rent flow represents the aggregate of the induction in all the coils, both positive and negative.

497. A second class of armatures is known as open coil armatures. Fig. 85 shows the principle of this class. Tracing the wire A we see the circuit is closed by the brushes B B′, while the wire C is open at D D′. Each coil has thus two terminals, and is open except for an instant when the commutator sections close the circuit through the brushes B B′. The best known armatures of this class are those of the Brush and the Thomson-Houston.

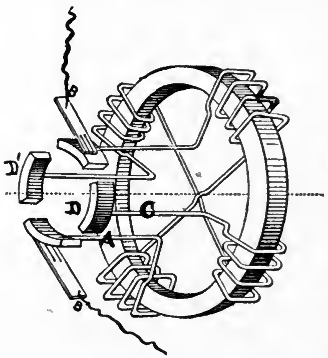


**Fig. 85.**

OPEN COIL RING ARMATURE.

498. The magnetic field in which the armature is revolved has been variously developed. The earliest attempt in that direction was by the use of permanent magnets, followed by electro-magnets in which current was obtained by the use of a battery, then by a separate dynamo called an exciter, and finally by sending the current generated through the coils of the field magnets on its way to the outside conductors.

499. In a previous chapter (225) the readiness with which iron and steel become magnetized through terrestrial induction is mentioned. The fact that it is almost impossible to commercially produce chemically pure iron in quantity, and the other fact mentioned, namely, the difficulty of permanently removing the magnetism in any piece of commercial iron, made the last improvement practicable.

500. Ordinarily there is a small amount of residual magnetism left in the core of the field coils. If now the arma-

ture is set in motion, and the terminals of the outside circuit connected so that all the current is thrown through the field coils, in a very short time the magnetism will have so grown or built up as to produce the required current.

501. Figures 86, 87 and 88 will fully illustrate the three forms of winding in use today. The first of these shows the "series wound" form, the entire current flowing through

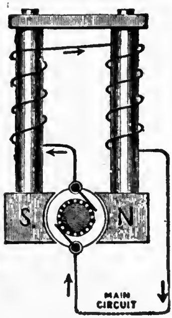



**Fig. 86.**

SERIES DYNAMO.

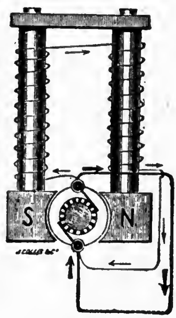



**Fig. 87.**

SHUNT DYNAMO.

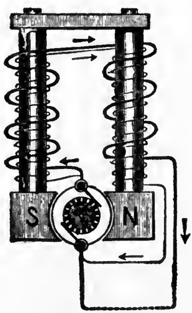



**Fig. 88.**

SERIES AND SHUNT DYNAMO.

the field coils; the second represents the "shunt wound," in which only a portion of the current flows through the fields; the third, or "compound wound," shows a combination of the two former, the current having two routes, both leading around the coils.

502. The series wound dynamo is used principally for developing a current of constant strength for arc lamps connected in series. The addition of a lamp demands an increase of voltage in the output of the machine. The action of a series wound dynamo in this respect is quite analogous to that of a galvanic battery arranged in series—the greater the resistance to be overcome the greater the number of

cells necessary for the purpose. Higher e. m. f. may be obtained by increased speed of the armature, when necessary.

503. The shunt wound machine is one which exemplifies the law of derived circuits. In derivation on the main wire, a thinner conductor leads a portion of the current through the field coils, the amount of current being entirely governed by the relative resistances of the main and shunt lines. The shunt wire being much thinner than the main, will of course carry much less current (381), and an increase in the resistance of the line will force a larger flow through the shunt, and thus increase the strength of the magnetic field, while a decrease of external resistance will reduce the strength of the shunt current proportionally. Shunt and compound wound machines are more practical for constant potential machines, for the reason given above.

504. A variation of the above windings is shown in Fig. 89. In this the shunt wire, instead of connecting with the upper brush, reaches across and is attached at the opposite side of the line, being a derived circuit on the line outside of the armature.

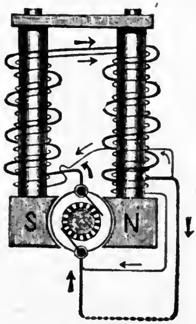



Fig. 89.

SERIES AND LONG SHUNT DYNAMO.

505. Other methods of governing constant-current machines are adopted, two of the best-known systems being shown in Fig. 90 (Brush) and Fig. 91 (Thomson-Houston).

506. Brush's regulator acts upon the principle of the variable conductivity of carbon under pressure. The current flows in the direction of the arrows. F-M represents the field magnets. B is a solenoid with its armature A so adjusted that when the circuit is normal the proper resistance is maintained in C, which is a pile of carbon plates, through which the shunt

circuit passes. Now, a lamp (L) being extinguished wi.l reduce the resistance, with a result of raising the current. This increase, acting on B, draws up the armature and com-

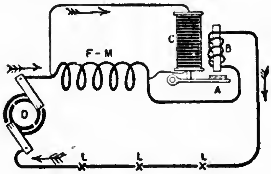



Fig. 90.

BRUSH REGULATOR.

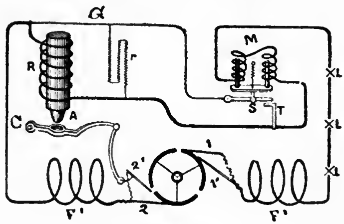



Fig. 91.

THOMSON-HOUSTON REGULATOR.

presses the pile of carbon plates, reducing the resistance of the shunt circuit, and allowing a greater portion of the current to flow outside of F-M, and reduce their magnetism.

507. In the Thomson-Houston system the regulation is accomplished by changing the position of the brushes on the commutator, relative to the lines of force. A combination of levers is so connected to the brushes that a movement of the armature of the magnet R, in either direction, will shift the brushes back or forward as required. This magnet R in a normal condition is inactive, being short circuited by the shunt line G, closed at T. The opening between S and T is governed by the strength of the controller magnets M. The operation is as follows: When the current from any cause becomes too strong, M acts, drawing up its armature, thus throwing more current through R, which immediately attracts the lever A centered at C, and shifts the brushes 1 1′, 2 2′. The contact lever S is in constant motion during the running of the machine, opening and closing the contacts S T by rapid vibrations.

508. It is evident from the illustration that one segment of the three-part commutator is always open, and that con-

sequently excessive sparking would naturally occur, with the result of rapidly burning out the brushes, as these broke contact. This trouble is conquered effectually by Prof. Thomson's air blast. Attached to the shaft of the armature of the machine a revolving pneumatic engine delivers an air blast in a series of gusts—three for each revolution—which blow out the spark at the instant when the brush leaves the commutator.

509. Two brushes are shown on either side of the commutator shafts, connected together, so that there is a lapping over from one segment to the next. The object of this is to render the flow of current more regular. The same arrangement is found in some other dynamos.

510. Another method of regulation has been suggested by several inventors, notably Brush and Deprez, in which an electro-magnet cuts in and out portions of the field, and attempts have been essayed at regulating the speed of the engine by electrical power from the lighting circuit, acting on electro-magnets; and in still other systems a small motor controls the shifting of the brushes.

511. Large dynamos, which are much more economical than smaller ones, are often so constructed that the armature passes through more than the two fields at each revolution. In such apparatus there are as many brushes as fields, a four-pole dynamo having four sets of brushes, etc. Such machines are classed generally as multipolar, to distinguish them from bipolar machines.

512. It will be noticed that in the illustrations, Figs. 86, 87, 88, 89, the brushes of the machine are not placed exactly horizontal or perpendicular to the poles, but at an angle towards the direction of motion. The lines of force, which in a state of rest would be directly across the intervening space, were there no disturbing influences present, are deflected when the armature is revolved, the neutral point being shifted, and the brushes have in consequence to be

set at an angle more or less acute. The cause of this distortion is found in the reactions, magnetic and electric, between the armature and the field, and it is called the lead of the brushes.

513. This lead of the brushes may require to be changed at any moment when conditions of resistance or speed vary, or there is a failure of the dynamos to accomplish a proper output of energy.

514. One of the indications of want of proper lead in the brushes is excessive sparking at the brush contact, but this may show also a want of perfect electrical and mechanical balance in the armature windings; the commutator may be worn, making imperfect contact, or the brushes fail to operate perfectly for want of trimming.

515. Shunt wound dynamos are regulated by means of a resistance box or rheostat, so placed in the circuit that by means of a switch lever any number of ohms required may be thrown into the circuit, while an instrument on the galvanometer principle indicates by a direct reading the number of volts going to line.

516. This is especially important in low tension (constant potential) lighting systems, where an exact, even pressure is required by economy, in both electrical output and destructive waste of lamps.

517. Before proceeding to consider the uses of the dynamo, there are some other phenomena which should be understood, resulting from the movement of the armature in the magnetic field, tending to complicate the results sought.

518. In the earlier forms of armature cores a coil of iron wire was made use of. Experience soon demonstrated the fact that there were currents flowing along the surface of the core, returning through the center of the iron. This is a useless expenditure of power, and is further detrimental in that the power so consumed is converted into heat within the core, that has a tendency to destroy the insulation.

These currents, because of their eddying through the iron of the core, are called eddy currents, and are also called foucault currents, from the French electrician Foucault, who made an exhaustive study of this form of current. They are also sometimes termed parasitical currents. Foucault currents may affect the pole pieces of the field magnets also, and thus to some extent impair their efficiency.

519. Another cause of heat and waste of power is found in molecular friction in the core. The constant changing of the molecules as the armature revolves is assumed to produce friction between the adjacent particles, resulting in heat. This effect, which is known as hysteresis, depends upon several factors: the rapidity of motion, the amount of moving mass, the density of the magnetism and the purity of the iron, all tend to influence the result. The best results in removing the hysteresis are obtained by the use of the purest and softest wrought iron, or pure annealed steel.

# CHAPTER XX.

## LIGHT AND POWER.—[CONTINUED.]

520. In the year 1808, Sir Humphrey Davy, the celebrated English scientist, delivered a lecture before the Royal Institution at which the first exhibition of an electric light was given. The electrical source was a battery of 2000 cells, the current of which, being broken at two carbon points, gave out the light and heat of the voltaic arc: the arc light of today. The experiment was a brilliant one, but was of little value from a commercial point of view, because of the expense. Faraday subsequently laid the foundation for the development of the dynamo, and for the commercial production of electricity for light, heat and power.

521. We have learned that when a dynamo is set in motion, and a perfect circuit is maintained, there is a current generated which is assumed to flow from the positive pole through the conductor to the negative pole, and thence to the place of beginning. Now this circuit may be made up of a combination of good and poor conductors, of larger and smaller wire, etc. We have learned that obstruction to the passage or flow of current always results in heat, and that this obstruction or resistance may be made to develop light, as well as heat.

522. This resistance to the flow of the dynamo current is the one indispensible factor in electric lighting. At a suitable position in the circuit, between the positive and negative poles of the dynamo, two cylinders of carbon are arranged end to end, so that the current passes across the pointed junction of the two. Now, when the two carbons are drawn slightly apart, the current is forced across the air space, the resistance of which converts the current into heat

and light. This, in few words, is the philosophy of the arc light, but to accomplish this, much complicated detail is necessary.

523. The heat of an electric arc of about 10 amperes at 45 volts is sufficiently high to disintegrate the carbon, reducing it to a vaporous condition; and this vapor fills the space between the carbon points. Being a much better conductor than the atmosphere, it will hold the arc readily. But experience has shown that the two carbons do not waste away equally—that carbon is constantly thrown off from the positive and deposited on the negative, so that the positive is wasted about twice as fast as the other. And again, after burning a short time, the shapes of the carbon tips, which at first were similarly formed, have materially changed. We see in the positive, a sort of inverted cup, called the crater, while the negative becomes still more pointed. Fig. 92.

**Fig. 92.**

THE ELECTRIC ARC.

524. The peculiar form of this crater, acting as a reflector, and the fact of the positive carbon consuming so much faster than the negative, give the first a preference as the upper carbon, for all positions where light is required

below the level of the lamp. The positive is usually the upper carbon.

525. As the consumption of carbon proceeds, of course the space or gap between the carbons widens, the resistance increases, until finally, unless otherwise provided for, the current would cease to flow and the light would be extinguished.

526. The laws governing resistances and current flow are again called into play, as will be seen by an examination of Fig. 93, which represents a series arc lamp regulator of the simplest form.

527. The current, arriving at L, as shown by the arrow, divides into two parts; the feebler portion passing through l, the upper spool, which is wound with finer wire and consequently has a higher resistance. It follows the course indicated by the arrow from T to the lower carbon holder at b, and to the next lamp at L′. The larger current passes through the lower spool, which is wound with coarser wire, thence to the movable lever connected with the upper carbon holder,

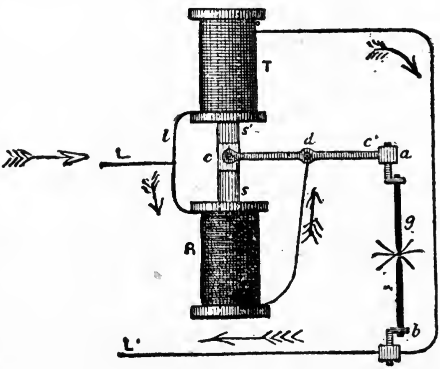



Fig. 93.

DIAGRAMMATIC ARC REGULATOR.

down the carbons g and h (across the gap), joining the feebler current at the lower holder, and thence to the next lamp. The resistances of the two spools are so proportioned

that only a small part—about one-hundredth—of the current passes the upper spool. A loose core, to which is attached the arm carrying the upper carbon, is drawn upward or downward, governed by the length, and consequently the resistance, of the arc.

528. Now, in a normal condition the core of the solenoid will drop, and the carbons will be separated. On throwing the current to line the upper coil will be energized, for the current will all flow around the gap between the carbons. The solenoid will suck in the core, carrying the inner end of the arm upward and lowering the opposite end. The gap between the carbons will close, and a second path be opened for the current through the coarser coil, which will overpower the upper one, and, pulling down the left end of the lever, open the gap and start the arc. This action, called feeding of the carbons, is repeated at every lengthening of the gap between them.

529. An ingenious method of regulation is shown in Fig. 94, differing somewhat from that which regulates after the method just described. In this the arc gap is closed by the gravity of the upper carbon holder R R. When current is thrown to line the electro-magnet M M is energized, the armature A A is attracted, but owing to its being held by the horizontal springs O and N, it can only move perpendicularly, carrying with it the curved lever C C, which clamps to and raises the rod R R, opening the gap between the carbons. The magnets M M are of peculiar construction, being wound with both large and small wire coils, but these are wound in opposition to each other. At the lower part of the figure is shown a disc of metal of which there are two, having slots punched in them. These form the plungers to a dash pot of glycerine, shown at G. The two discs are so arranged relatively to the openings mentioned as to regulate the speed of the plunger.

530. The two carbons being in contact, the current passes

down the larger wire of the two coils, following the course of the two arrows, down R through the carbons, from the lower carbon holder to the negative terminal towards the next lamp. The magnets M M, acting as described, open the gap and strike the arc, which burns until the width of the gap increases the resistance so that the current flowing in the shunt of finer wire overcomes that in the coarser coils of M M, when the armature A A is released, the clamps cease to hold the rod R R, and gravity closes the gap sufficiently to allow the former action of attraction and clamping to be repeated. The dash pot meantime prevents a too sudden action of the carbon. Fig. 95 shows still another form of lamp, the regulator acting through the medium of clockwork, with a pendulum attachment in place of a dash pot.

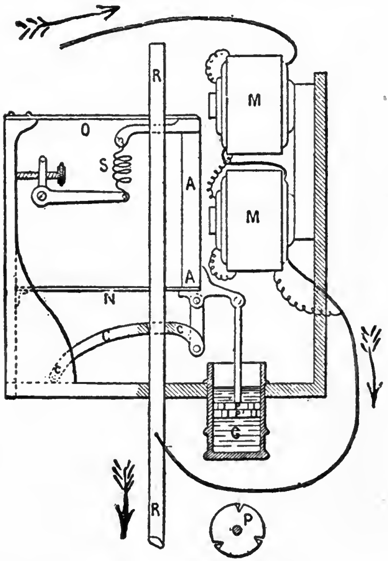



**Fig. 94.**

ARC REGULATOR.

531. In all series lamps there are, or should be, an automatic switch, which, when the carbon is burned short, will close a short circuit, cutting out the lamp, thus preventing the burning out of the holder.

532. The ordinary lamp is only arranged to burn seven or eight hours without retrimming. For an all night service what are called double lamps are made, having two upper and two lower carbons. An automatic switch changes the circuit from the exhausted half to the second, at the proper time, saving the trimming of the lamp at an unseasonable hour. Still other lamps have but three carbons, the negative being broad enough to act in place of the two in the last named variety.

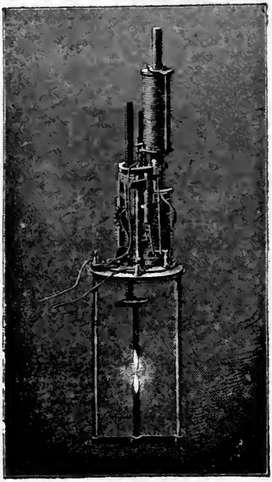


Fig. 95.

CLOCKWORK REGULATOR.

533. The current of the many series arc circuit systems varies between 4 and 9.6 amperes. The pressure of the current is from 45 to 50 volts per lamp, and the lamp of 450 watts is usually called a 2000 candle-power lamp. The light of the lamp is most brilliant at a downward angle of about 45 degrees, and less than this both above and below that angle. The actual candle power is difficult to determine, because of the constant shifting of the crater, which is a reflector, but it is far below the figures usually named.

534. The carbons used in arc lamps are extremely hard and dense. They are made from a mixture of powdered gas house coke, ground very fine, and a liquid like molasses, coal tar, or some similar hydro-carbon, forming a stiff, homogeneous paste. This is molded into rods or pencils of required size and length, or other shapes, being solidified

under powerful hydrostatic pressure. The molded articles are now removed and allowed to dry, after which they are placed in crucibles or ovens, thoroughly covered with powdered carbon, either lamp black or plumbago, and baked for several hours at a high temperature. After cooling they are sometimes repeatedly treated to a soaking bath of some fluid hydro-carbon, alternated with baking, until the product is dense as possible, all pores and openings having been filled solid. Arc carbons are often plated with copper by electrolysis, to insure better conductivity.

535. The density of one of these electrodes may be shown by placing a piece of the carbon in a coal grate fire, where it will remain for some hours before being entirely consumed.

536. Carbons in which there is a core of softer material are claimed to produce a steadier and better light than those of perfectly solid cores, the softer portion, because of its more rapidly vaporizing, keeping the contacts nearer perfectly centered. The cored carbon was an European invention.

537. The series arc, as its name would indicate, has the most simple of all lighting circuits. The lamps are arranged so that all the current from the positive pole of the dynamo goes through each, and from the last one the conductor leads back to the dynamo. This is shown in Figs. 86 to 89 inclusive.

538. The different forms of winding to best satisfy the requirements of the dynamo have been shown, but there are other equally important factors in their construction. The size and output of the machine, whether for constant potential or constant current, have all to be calculated for. The proper size and length of conductor, both in the armature and in the field coils, and the speed at which the armature is to revolve, are also matters of no small importance. There are shop secrets in the works of many constructors,

which in some cases have only been confided to superintendents of construction, after these have been bound by oath not to reveal them.

539. Thus far the lights which have been considered are not of a character to be used—save to a limited extent—within doors, but are appropriate for out of doors lighting, depots, business houses, etc., where the danger from fire is a minimum.

540. The introduction of the incandescent or glow lamp filled a want which the arc lamp was incapable of supplying. The latter is too glaring, too unsteady, too dangerous to life and property except as mentioned; but the former, less dangerous to handle, capable of being made portable, small, convenient in every way, has fought a successful battle against all opposition, and holds an impregnable position against its many adversaries.

541. The dynamo for an incandescent circuit differs from the arc dynamo in several particulars, but principally in this: The series arc dynamo is constructed and regulated to feed a given number of lamps at an arranged amperage of current, but with a fixed predetermined voltage for each

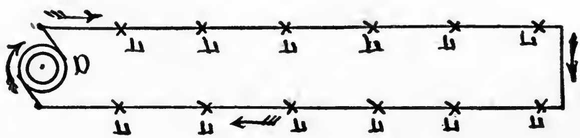



Fig. 96.

CONSTANT CURRENT CIRCUIT.

lamp. The incandescent dynamo develops a current which is made to vary in strength with the number of lamps, while its voltage remains fixed under all circumstances. The

former is known as a constant current system—the latter as a constant potential system.

542. The two systems are illustrated in a general way in Figs 96 and 97. The first of these, the arc circuit, shows the current passing through all the lamps, L, from the dynamo D, in the direction of the arrows. The dynamo is wound for the given number of lamps, each of which requires a known number of volts of pressure to overcome the resistance of the arc gap at X. The flow of current remains constant, while the potential is varied to correspond to the number of lights in service, and it is evident that the opening of the line at a lamp or between two of these would cut off the current and extinguish them all. In each lamp there is a shunt line around the arc gap, so that when a lamp is inactive the current will still feed the rest of the circuit. There is also an automatic switch which cuts the lamp out when the carbon is exhausted, as well as a hand switch connecting the two terminals on top of the lamp.

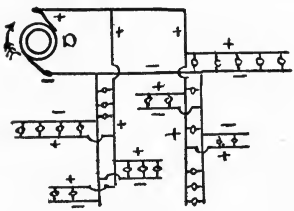


**Fig. 97.**

CONSTANT POTENTIAL.

543. In the multiple arc or parallel circuit we find quite a different arrangement. The current is divided—distributed among the lamps—each being accorded its share, proportioned inversely to its resistance. The lamps serve as bridges or paths over or through which the current flows from the + to the − conductor, and it is evident that the more of these there are the larger the body of current which will flow. The opening of a conductor anywhere, save at that portion between the dynamo and the first branch, will only cut off part of the installation. These two main wires carry all the current, and are proportionately larger than those in the

branches. At each succeeding branch the requirements are diminished, and the wire grows less until a minimum is reached. At all such changes of size it is usual to place a fuse or safety device, which, in case of an increase of current, due to a crossing of the lines or to an accidental grounding of the conductors, will melt, having a lower carrying capacity than the wires beyond it, and thus automatically open the circuit and prevent harm. One of these should be placed on either conductor to protect the smaller wire. The fuses increase in size, and consequently in carrying capacity, as we near the dynamo, D, and at the machine are found fuses large enough to carry the entire output of the dynamo.

544. Each group of lamps is controlled by a switch, which will cut off the current by opening one or both branch conductors running to that group. This switch, to insure perfect safety, should open both lines simultaneously, and is called a double pole switch. A single pole switch opens but one of the conductors. The key at the lamp, which is a single pole switch, is often omitted where the entire group is lighted and extinguished as a whole, as in chandeliers, or in the illumination of large interiors, such as theaters, lecture rooms, etc. The key socket is inserted where only a portion of a group or a single lamp is used at any time.

545. The connections between the lamp and the line are made through the socket, into which the base of the lamp is screwed. The socket has two metal surfaces which make contact with the filament of the lamp inside the globe through metallic connections. The filament thus becomes a bridge between the two conductors, when current is turned on.

546. Here we have another instance of the heat developed through resistance to the flow of current. The carbon filament is quite thin, and of a high resistance. In traversing this conductor the current heats it to incandescence.

Being made of carbon it would instantly consume if there were any oxygen within the globe.

547. In the course of construction a very nearly perfect vacuum is formed within the bulb by means of a mercury pump, and the globe is sealed by fusing the neck of the tube leading to the pump, producing the pointed tip of ordinary lamps.

548. While the ordinary system of incandescent current distribution is that shown in Fig. 97, there are other methods formerly in vogue, but which, save for specific purposes, have been superseded by the transformer systems of distribution. The series multiple and multiple series systems are shown in Figs. 98 and 99. In the first of these the current of the dynamo must be a constant quantity—such an amount as divided by the number of lamps will give those of each group their proper share. The electro-motive force of the dynamo is variable, depending on the number of groups. Arc lights, L, may be operated on such a circuit, but must be specially adjusted for the purpose. In the multiple series circuit each group of lamps, as a whole, equals the voltage generated by the dynamo. In the case of street railways the generator commonly develops current at 500 volts. Then five 100-volt lamps in series are required for that voltage. This enables these transportation companies to light a street car with their motor current. Their shops, depots, tunnels and signal lamps are thus lighted in groups.

549. The multiple series system of distribution is taken advantage of for temporary decorations, window displays, and the like, where miniature lamps are used on a 110 or 120-volt circuit. A sufficient number of lamps are connected in series to bring down the voltage as above.

550. Still another form of circuit is shown in Fig. 100 This is known as the three-wire system. Two dynamos are shown, so connected that the + pole of one is connected to the − pole of the other, while connected to this junction is

a third wire called the neutral. The two outside wires form one side of the lamp circuit, and the neutral forms the other.

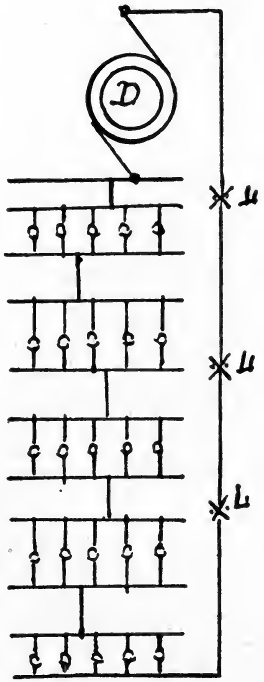



**Fig. 98.**

SERIES MULTIPLE.

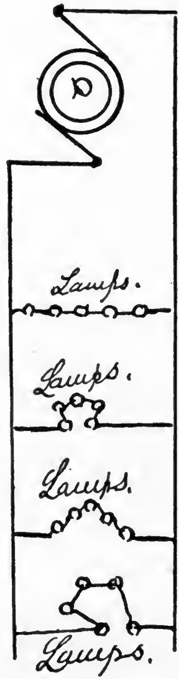



**Fig. 99.**

MULTIPLE SERIES.

Now, when the two generators are doing equal work, and the two sides of the circuit have an equal number of lamps,

the neutral wire will show no current, it being on the + side of one dynamo and the − side of the other.

551. This combination is an excellent one where it is desired to use two voltages at different points, as for instance, 110 volts for lamps and 220 volts for a motor service. Two 110-volt dynamos as shown would accomplish this result, for between either side and the neutral there would be only the output of one machine, while a connection between the two outside wires would carry the output of the two in series, or 220 volts.

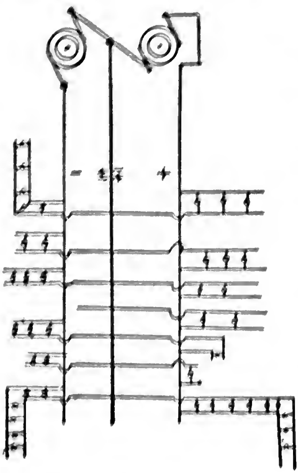


Fig. 100.

THREE WIRE.

552. Another advantage, and a far more important one, is the saving of copper in the line, very much less being required than for a two-wire system. The actual weight of the former is claimed to be about three-eighths that of the latter.

553. A still further complication of current distribution is seen in a five wire installation. This has not been very generally adopted in this country. Four dynamos, A, B, C, D, are connected in a generally similar manner to that in the three wire system. This invention is credited to the Siemens & Halske Co. Its advantage is principally in the saving of copper, but it is more difficult to keep in balance than the former, a matter of no inconsiderable importance.

## CHAPTER XXI.

### LIGHT AND POWER.—[CONCLUDED.].

554. While great similarity exists between a dynamo machine and an electric motor, there are marked differences which distinguish the one from the other. For instance, the dynamo is a machine for developing current, while the motor is a device for developing mechanical power from electrical power—a transforming of one form of power into another form. The motor is dependent on some source of current for its ability to accomplish work, while the dynamo requires the application of mechanical power to develop current.

555. Again, while all forms of dynamos may be made to run as motors, in the majority of cases the motion of rotation will be the reverse of that which would be developed were the machine run as a dynamo. In a dynamo the development of current is a result of moving a conductor in a magnetic field; the movement of a motor is the result of mutual attraction and repulsion between the field magnets and the magnetized armature core. The magnetism in the core is produced by the electric current flowing through the wire windings on the core. The direction of this current is so controlled by the commutator as to create magnetic poles in the armature core at the right positions to give the strongest attractions and repulsions to the field magnetism at all times.

556. Those dynamos which, being run as a motor will have a reversed motion, are:

(*a*) A magneto dynamo;
(*b*) A separately excited dynamo;
(*c*) A series dynamo;
(*d*) A compound wound dynamo,

if the series winding is more powerful than the shunt, but in the same direction if the shunt is the more powerful. A shunt dynamo run as a motor will have the same direction of rotation as if run as a dynamo.

557. When the revolving armature of a dynamo develops a current which in turn magnetizes the armature differently from the way in which it is magnetized from the field, and thereby tends to retard the motion of the armature, it requires power to overcome this tendency. The total electrical power of the dynamo is that which is exerted on the armature after deducting the losses due to mechanical and magnetic friction; and the available electrical power which the dynamo sends to line is the total power generated after deducting losses from heat.

558. The same losses exist in converting electrical energy into mechanical energy, by a motor, and hence the amount of mechanical energy made available by the motor will be less than the applied electrical energy.

559. Jacobi first explained the action of the counter e. m. f. set up by the revolving motor armature which cuts down the current feeding it, and also the corresponding effect which is seen when the load is thrown upon a dynamo. Jacobi's law is stated as follows: The maximum work done by any motor is accomplished when the counter electro-motive force is equal to one-half the impressed e. m. f. The counter electro-motive force acts as a resistance to the flow of the impressed current, choking it back, so that the faster the movement of the motor the less current is used. Now, when a load is put upon the motor its speed is reduced mechanically, and this reduction permits a greater current flow because of the reduced counter e. m. f.; and we thus see that this "spurious resistance," as it is sometimes called, is a very important factor as a regulator and economizer of current.

560. In all that has preceded, the currents considered have been what are known as continuous currents, regardless of their strength or pressure. Continuous currents are defined as currents which flow in one direction continuously, in contradistinction to a current which flows alternately in opposite directions and is not straightened or rectified by the commutator of the dynamo. In place of the commutator on an alternator there are two or more perfect rings, connected each with one of the terminals of the armature. The brushes rest on these, and it is evident that as the armature revolves it will develop a positive current during one-half of its revolution and a negative current during the other half, which will of course send a constantly reversing current to line. Fig. 101 will perhaps assist in illustrating this form of current.

561. The sinuous line A B graphically represents the current flow, that portion above the horizontal line the positive and that below the line the negative impulse. The fig-

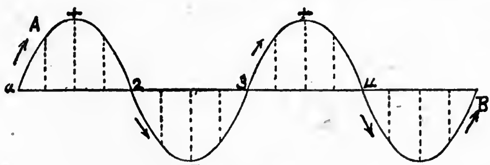



**Fig. 101.**

ALTERNATE CURRENT CURVE.

ure represents two complete cycles of alternations. The positive electro-motive force increases between a and +, then decreases, reaching zero at 2, where it changes to negative and increases to —, then decreases till reaching 3, where it again reverses, etc.

562. These variations represented by the curves A, +, 2,

and 2, —, 3, represent one complete alternation. We must not confound the intermittent current with the alternate current. The former is simply a current which is of but one direction, but which flows and ceases alternately.

563. While the general principle of alternate current developing machines is the same in all, different methods of arriving at the same result are practiced. The nature of the alternating current is such that it will not energize the field magnets, for the reason that each magnetic effect is annulled by the succeeding impulse, and it is therefore necessary that some provision be made for energizing the field magnets. This is sometimes accomplished by commuting a portion of the current, sending it through the field coils, sometimes (and most generally) using the current generated by a separate, direct-current dynamo; and again by a combination of the first and a commuted current from the secondary of a transformer. Further, the armature, which we have heretofore considered as the moving part of a dynamo, may be stationary while the field revolves; or the two may move simultaneously in opposite directions, or the armature may revolve about the fields.

564. The changes graphically represented in Fig. 101 are reckoned by the number of complete cycles per second—of which two are shown—and this number is known as its complete alternations. The changes of direction are, of course, twice that number; and where the number of alternations per minute is given, this should be divided (since two alternations are required for one period) by the number of seconds in a minute, multiplied by 2, (equal to 120). The complete cycle is accomplished in a minute fraction of a second, which is called a period.

565. In order to increase the number of reversals in a unit of time the armature may be made up of a number of coils alternately reversed, as shown in Fig. 102. It is evi-

dent that these coils passing the pole pieces of the fields will have induced in them six alternations, or three complete cycles or periods for each revolution of the armature. The field coils for use with this form of armature are shown

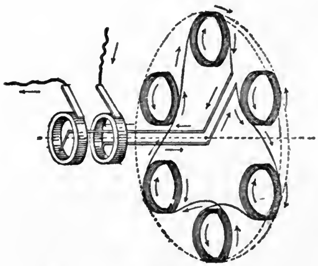


**Fig. 102.**

ARMATURE OF AN ALTERNATING DYNAMO.

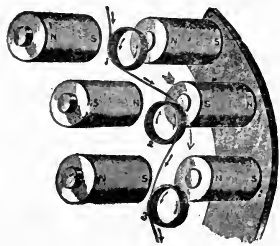


**Fig. 103.**

FIELDS OF AN ALTERNATING DYNAMO.

in Fig. 103. Other methods of winding are practiced. The coils may be laid in the grooves of a drum armature core.

566. Ohm's law teaches us that there is more or less resistance to a current of electricity in all conductors, and that the amount of current is equal to the original e. m. f. divided by the resistance. The difficulty of maintaining a heavy current at a considerable distance from the fountain head in a direct-current system is readily apparent. The expense of conductors increases rapidly as the distance is augmented, until the cost is prohibitory.

567. It was this condition of affairs which brought out the alternating system of current, and with the assistance of the transformer rendered it possible to furnish large currents at low voltage, or to vary the proportions of these factors as desired, at a distance, economically.

568. We have learned how an inductive action occurs

when a current is alternately made and broken at the dynamo. This alternate action, occurring in a coil which is in close proximity to a second coil, will set up corresponding (but reversed) impulses in the second coil. Further, the quality of the impulses in the second coil will be entirely governed by the relative sizes of the wires, and the number of turns of wire in the coils. If the primary or inducing coil has less turns than the secondary or induced coil, the induced current will have a much higher e. m. f. than the inducing current, but its amperage or current strength will be much less; and on the other hand if the inducing current flows through the greater number of turns, then the induced current manifest in the other coil will show exactly reversed phenomena. The proportion maintained between the two factors (pressure and current) will be such that the watts will remain virtually constant under all changes.

569. The advantages to be gained by the use of transformers are many and important, chief among which is economy in the distribution of current at a distance. The primary wire, carrying a current of high potential but low amperage, requires but a comparatively thin conductor. The secondary, which is a much shorter line than the primary, being required to carry a current of lower potential but greater strength, must needs be of greater carrying capacity. A second advantage in this method of distribution is one affecting the insulation of the patron's installation. As the conductor which furnishes the power or light is a comparatively short one, the faults of insulation are more readily found and corrected; and the faults of the various installations do not affect each other, but are local, while the faults of the main or primary line—leaks, grounds, etc.—do not materially affect the secondary installations. There is also this advantage in the transformer system: that different voltages may be furnished as required, from the same source, by changing the relative proportions of the trans-

former coils; and the economy in fuel and labor is also in favor of this form of distribution.

570. The expense of transformers, on the other hand, is

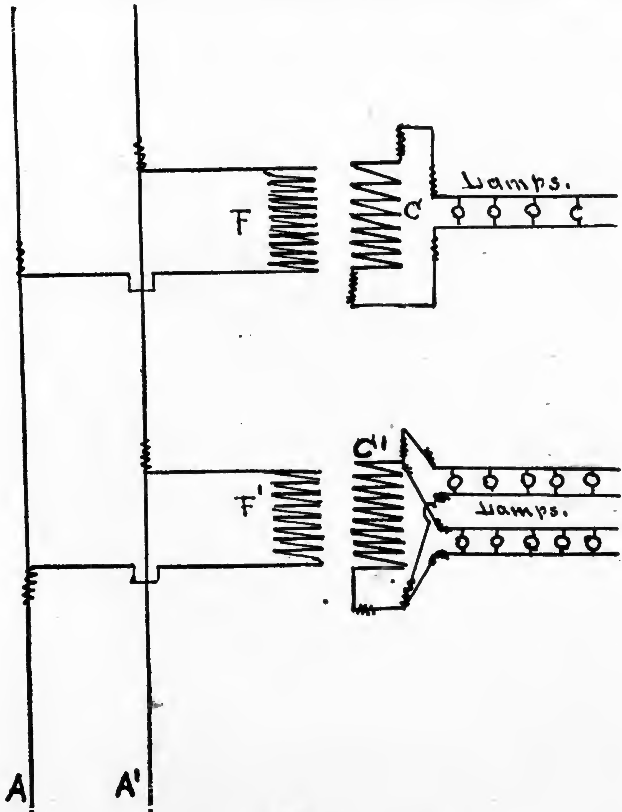



Fig. 104.
TRANSFORMER CIRCUIT.

by no means inconsiderable, but these are not installed save as they are needed, so that the investment is a paying one from the date of installation.

571. Fig. 104 will illustrate the principle of the transformer. The alternate current arrives at the transformer through the wires branched from A A′. F F′ represent the primary coils, which have no metallic connection with the secondary coils C C′. From these latter coils the induced current, which is of less pressure but of greater strength, is carried to the lamps.

572. Were the amount of current flowing through F and F′ dependent solely on the true resistance of the conductor (as given in resistance tables), the transformer would be a very wasteful piece of apparatus, and as much energy would be expended when the lamps were shut off as when they were all lighted. The induction of the various turns of the wire in F upon each other. chokes down the current when the lamps are cut off, which leaves the secondary coil open. This choking down of the flow in F is almost complete. It acts as a dam, and forces the current to keep on its way through A and A′. Remember that at each transformer the current has two routes, the primary wires being connected up in multiple arc with all the transformers.

573. Now we will suppose that a light is turned on in the circuit of C. The resistance of this circuit is thus lessened, and a small amount of current will now flow through the coil and the lamp, and this current will set up a counter or mutual induction, which will react on F and thus relieve a portion of the choking effect. Thus with more and more current, more and more counter induction will continue to increase with the flow, until the lamp is up to its proper candle power. These phenomena will follow the turning on of more lights, until the capacity of the transformer is reached—a point where the self-induction of the primary is

balanced by mutual induction. If more lights are now placed on the secondary circuit, C, or if by any other means the resistance of the circuit is lessened, as by crossing the lines or by using lamps of greater candle power, the wires of both the primary and secondary would be called upon to carry an unsafe strength of current. To prevent an accident from such causes, the primary and secondary are both provided with fuses, which melt before the danger point is reached, and thus open the line.

574. The losses due to transformation are greater in proportion in the smaller sizes of transformers, and for this reason the larger ones are preferred by most electric light companies. It is also true that all converters are most economical when loaded to their full working capacity, for the losses vary but little under any conditions of loads.

575. The constant demand for transformers of greater capacity early induced electrical inventors to turn their attention to improving this form of distribution; and as these pieces of apparatus grew in size, better insulation was required. Currents of such high voltage were used that the primary often broke down the insulation and crossed to the secondary, destroying the transformer, and even starting a conflagration. In an improved transformer the safety fuses cannot be replaced except when the line is open. The fuse holders are on the inside of the door of the transformer, which breaks both sides of the primary when it is opened, thus reducing the danger of re-fusing a line circuit to a minimum.

576. A very radical improvement in the line of insulation consists in the immersion of the entire transformer in a case filled with insulating oil, which finds its way into every part of the apparatus, raising the insulation at every point, and effectually preventing the possibility of moist-

ure. Now, when from any cause there happens a spark discharge from the primary to the secondary, or to the iron case of the transformer, the puncture is immediately closed by the oil, and the weak spot is at once repaired by its insulating properties.

577. A second system of converting energy from either higher or lower potential is generally known as a rotary converter system, and while less applicable than the systems before mentioned, there are cases where it has proven of much value.

578. The rotary converter is made up of a motor run by a high potential current and a dynamo upon the same shaft, which, by its winding is calculated to develop the required current at a known pressure. The windings of the two machines are often placed upon the same shaft, so that the same fields serve for both. The armature has two sets of brushes, often at opposite ends of the shaft, and the two systems are as perfectly independent as if they were at opposite ends of the room and connected by a belt. Thus a high pressure current may be brought from a distant power station upon a comparatively thin conductor, and made to run one or more motors, which in turn will furnish a current through this action of the attached dynamo, of proper strength for lighting, heating, for telegraphic purposes or driving machinery or fans. A current of many thousand volts pressure may thus be "stepped down," as it is sometimes termed, to the proper voltage for any of the above purposes. The reverse process—raising the voltage of a current by a similar or any other system—is termed "stepping up"—so that we have step down and step up transformers, designating the character of the conversion.

579. Another valuable property of the alternating cur-

rent is the facility which it offers for the simultaneous development of two or more currents.

580. The collectors of current on all the generators which have been shown are so situated upon the commutators as to conduct away all the current at that point in the armature revolution where the voltage is at or very near a maximum. A second pair of collecting brushes may be placed at right angles to these, and with proper windings and connections it is possible to collect part of the output of the generator at each of these two pairs of contacts, so that with a generator developing 500 volts we may have two independent circuits of 250 volts each from the same generator, and we may in the same manner with three distinct windings and collectors, have three instead of one circuit from the dynamo. In all cases, however, the legs of the circuit, as they are called, must be balanced so that each shall carry approximately the same amount of current. The primary object of this system is the distribution of power through motors.

581. Fig. 105 will illustrate the method of accomplishing this in a system of three phases. The three currents are represented by the lines 1, 2, 3, and the three wires are shown in cross section at a, b and c. The circuit of the first current is composed of the line a b, the second of b c, and the third of c a.

582. On either of these three circuits motors may be placed, and the alternator may be generating a dangerous current if it were all delivered over a single conductor, but owing to this division of the output, the voltage is economically brought down to a safe pressure.

583. Motors which are actuated by alternate current, whether this is from a single phase or multiphase gener-

ator, are called induction motors. In such a motor the current is brought to the field magnet by the three wires shown in Fig. 105, alternately, and returned as stated. This field magnet, Fig. 106, consists of a soft (iron or steel) ring, wound with the coils R R R, connected to the wires a b c. The armature is usually of the drum form, such as has been heretofore shown, built up of thin iron discs to break up Foucault currents. Around this, parallel with the shaft of the armature are laid heavy copper rods, thoroughly insulated, in grooves. These are connected by rings at the ends of the drum, or as shown in Fig. 106. As the three currents follow each other alternately, their magnetic effects follow in a similar manner around the ring; and the three currents operating thus together, give to the fields an inductive power equal to that of the total output of the generator. This rapidly rotating magnetic field set up by the current in the windings R R R, induces currents in the armature windings, and these in turn set up a counter e. m. f. as has been explained, and the armature revolves in almost perfect synchronism with the rotating field.

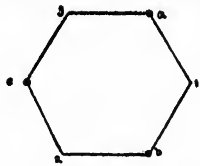


**Fig. 105.**

THREE PHASE PRINCIPLE.

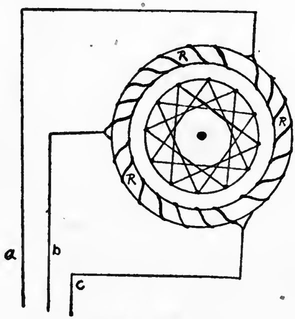



**Fig. 106.**

THREE PHASE INDUCTION MOTOR.

584. A peculiar method of distribution of alternate current for illumination, with an occasional motor, is known as the monocyclic system. In this system the lighting load

is entirely connected to one single phase circuit, while the

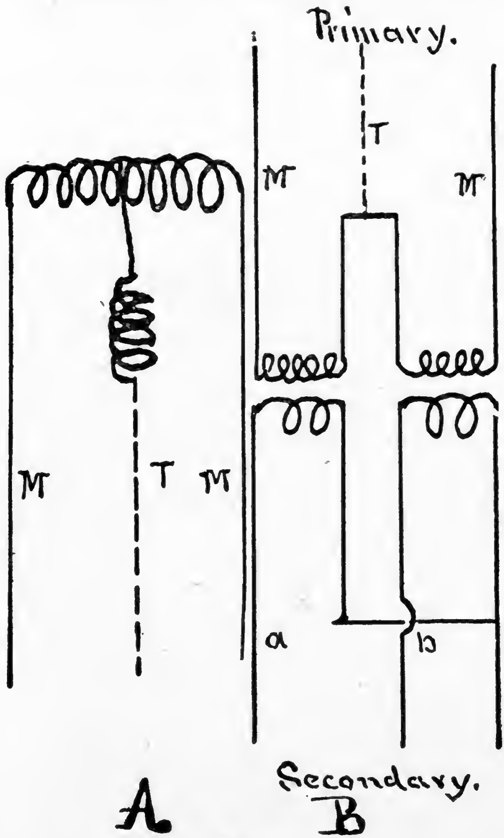



Fig. 107.

MONOCYCLIC ALTERNATOR.

motors are started and operated by means of a third wire, known as the teaser wire.

585. Fig. 107, A and B, will assist in understanding the windings of the monocyclic alternator. There are three collector rings; those from wires M M as in an ordinary single phase alternator. The third collector ring is connected to the teaser wire T, which has a separate winding on the same core, and is joined for its other terminal to the main primary winding. Conductors for lighting circuits are connected to the main collector rings; but where a three phase motor is to be installed, a connection is made on one side to the teaser wire, and the other terminals to the other two lines, which completes the three phase circuit and sets up a rotating field similar to that from a three phase alternator.

586. A single phase motor is also known as a uni-phase motor, which is perhaps a preferable term for the machine. Two phase motors are also called di-phase, and a three phase motor is a tri-phase, while multiphase and polyphase are terms descriptive of that class of machinery to which the 2 and 3 phase machines belong.

587. The uses of motors are so varied, and they are becoming so universal as to preclude the necessity of special mention. Electricians have developed so many and varied forms of utilizing electrical energy for the production of mechanical motion that a mere mention of the names of inventors in that line would fill a page or more of this work. The applications range from the desk fan, requiring an ampere or less of current and developing approximately an eighth of a horse-power to the giant machines which actuate the movements of passenger cars on electric roads. There is of course a loss of power in the conversion of electric into mechanical power, but this loss is less than that sustained in accomplishing similar results through the shafting and

belting necessary in the use of steam, or in the cooling of the steam where this is carried some distance before its application. The electric current is economically carried through long distances, and applied where needed. The loss in the transmission of steam power by belts and shafting is in many instances as high as 33 per cent. to 50 per cent.. while the loss in electrical transmission may be as low as 25 per cent. to 35 per cent. with a system of approved distribution.

588. A comparatively recent improvement is still more economical, and obviates the use of belting between the dynamo and engine, both being direct connected. Motors too, are put in the same intimate relation, in elevators and in other moving machinery.

589. In connection with storage battery outfits, street cars, carriages, yachts and launches may be both run and lighted more safely than by any other source of energy, and the unpleasant features of heat, smell and dirt unavoidable with the use of steam or volatile inflammable substances, avoided.

590. The use of automatic attachments for starting and stopping motors, and for protecting them from overloading which might endanger the safety of the machine are both numerous and ingenious as well as effective. An arrangement of the first named attachment is a simple switch lever attached to a flexible wire rope over a pully, at the lower extremity of which is a weighted float. When the water rises to a certain level the float rises, the weighted lever drops, throwing in the switch, and starting a motor attached to a rotary pump. The water being reduced to a safe level, the descent of the float by reverse action opens the switch, and thus prevents a waste of current. This is adaptable in sub-

basements, warehouses, vessels, etc., and in the latter case would be a tell-tale of a leak which might become serious if not discovered.

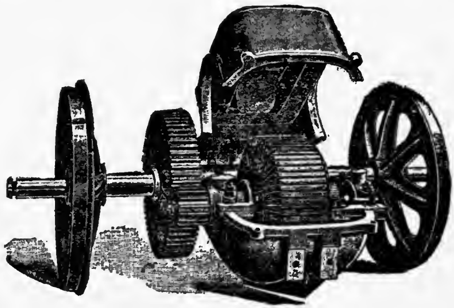


Fig. 108.

STREET CAR MOTOR.

591. An overload switch has an attachment actuated by an electro-magnet which acts just before the danger point is reached, and opens the line, bringing the motor to a sudden stop. This is sometimes enclosed in a locked cabinet, to prevent tampering with it by employes who are doing piece work, and who would otherwise overload the motor and damage it by burning out the coils. Underload switches are also used.

592. Motors on street railroads may be run by storage batteries, or by current direct from the power houses. In the latter case the overhead wire leads along the track, sometimes in the centre overhead, sometimes (but rarely) at one side of the road. Contact is made through the trolley, to the motor, which is usually attached to the axle or to the truck (sometimes at both ends of the car,) and from there contact is to the wheels, through the rail and ground, back to the power house.

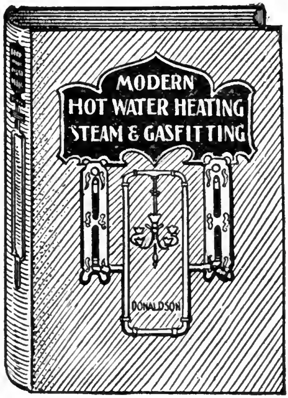
593. The railroad motor is completely inclosed to prevent mechanical injury, the entrance of snow, water or dirt. The parts are readily reached for removal or adjustment through the ease with which the two halves of the cover are

opened. The circuits are arranged in multiple arc so that either end of the car may be the front, and there are duplicates of resistance coils, levers, etc.

594. The rapid revolutions of the motor armature is such that its speed requires to be reduced by gearing. The hum of the motor rises in pitch as the speed increases. This reduction of speed is shown in Fig. 108, which also indicates the method of getting at the inner portion of the motor by opening the case, for repairs or cleaning.

595. Motors are used for a great number of purposes. The handling of heavy castings by overhead railways in foundries and machine shops; in the transferring of baggage in some central railway stations; in printing establishments; in a great variety of manufacturing concerns; the turning of wood and of iron, and in almost every conceivable form of lathe or of drill, motors have been found applicable where electricity is obtainable. Yet the ingenuity of the electrical inventor has still a wide field for the exercise of his talents.

**THE END.**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